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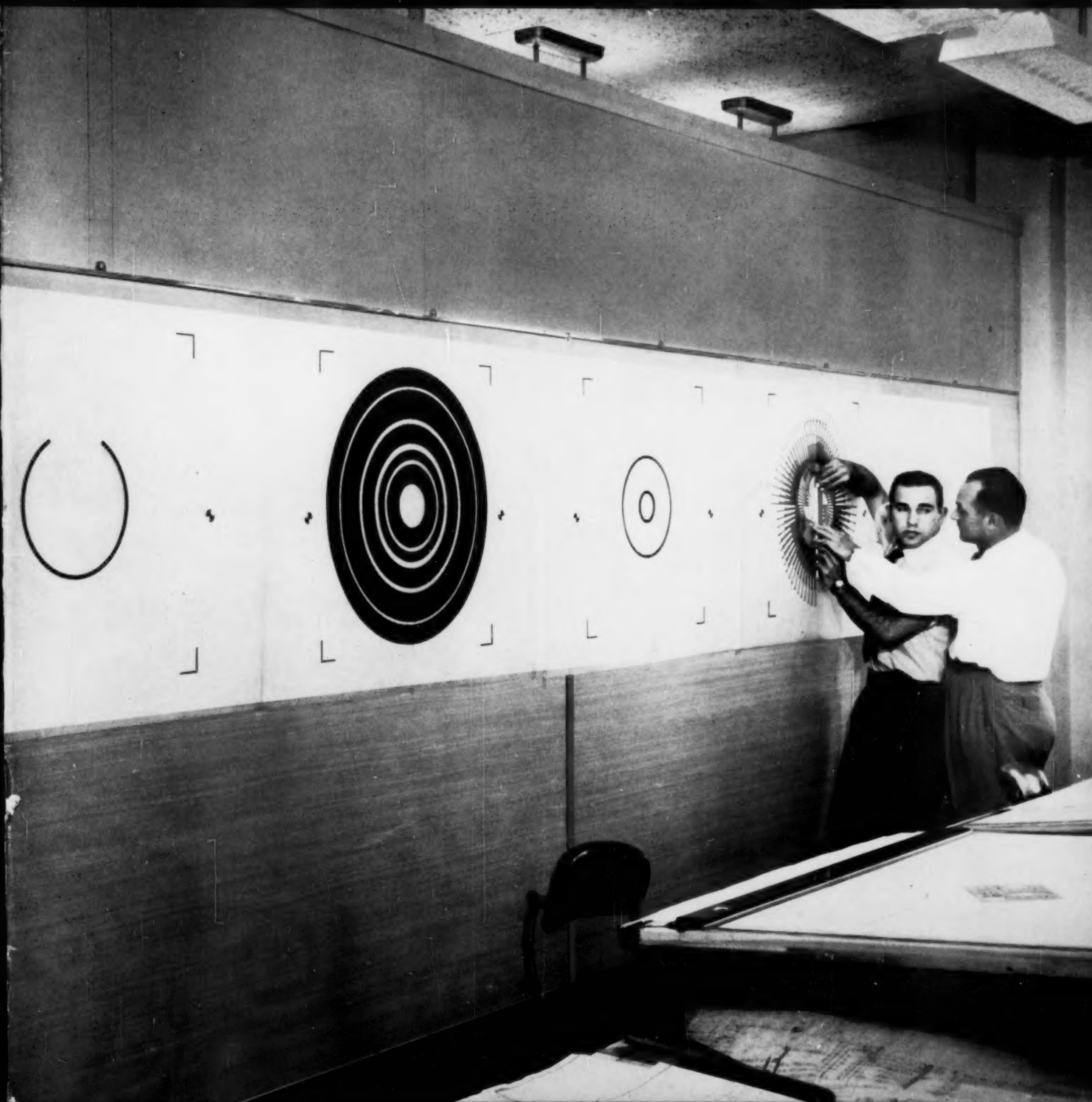

Bell Laboratories RECORD

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THE COVER: B. Behler (left) and J. Novotny discussing master layouts of printed circuits (see opposite page).

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Printed Circuits

N. OSIFCHIN and S. J. STOCKFLETH

Electro-Mechanical Development

Until recently, the extent to which complex electronic equipment could be decreased in size as a result of the new family of miniature devices — transistors, thermistors, semiconductor diodes — was limited to a large degree by the physical space required for conventional wiring. This limitation has been largely overcome in many applications by the growing use of printed-circuit techniques. Considerable development work has been done in this area at the Laboratories, particularly in fundamental studies on raw materials, and the physical and electrical characteristics of printed wiring.

The traditional method of building electronic equipment is being challenged today more than at any time in the history of the industry. The impetus stems from the invention of the transistor, which opened a new era of electronic devices, and from the rising costs of fabricating and maintaining the complex electronic systems planned for telephone, military and data-handling systems.

To cope with this situation, the designers must adopt more efficient concepts which will result in equipment that is dependable, inexpensive, simple to build and easy to maintain. One concept steadily gaining recognition in new development projects is the "unit assembly" or "modular" technique with "printed circuits" as the basic building block. With this technique, the highly repetitive low-power and low-voltage circuitry prevalent in most new electronic systems is divided and packaged into logical groups which perform specific functions, such as voltage amplification, binary counting, and so on. Each of these may be a module consisting of a single printed-wiring board which contains all of the components, as illustrated in Figures 1 and 2, or it may consist of a printed interconnecting wiring board and several submodules as illustrated in Figure 3. In either case, the printed wiring board is the basic unit of the system.

The term "printed wiring" implies that the conductors which interconnect conventional electrical components are produced on an insulating base by any process which does not employ conventional wiring. "Printed circuits," often used interchangeably with "printed wiring," implies that resistors, capacitors and inductors are also printed.

There are at least twenty known methods of producing printed wiring. Among these, six of the most commonly used may be generally classified as the "printed or painted wire," the "plated wire," the "embossed wire," the "stamped wire," the "transfer" and the "etched wire" processes.

In the printed or painted wire processes, finely divided silver or copper dispersed in a lacquer or ink carrier is applied to an insulating board by spraying or brushing through a stencil or by offset printing. The printed path is then made conductive by removing the organic carrier which separates the metallic particles. In the case of ceramic boards, this is done by the application of heat. Where plastics are used, volatile solvents are normally incorporated in the carrier; also a small amount of

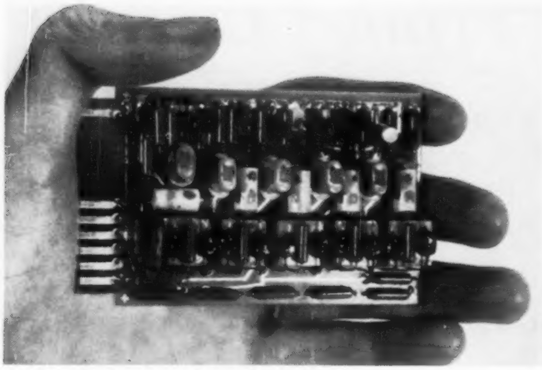

Fig. 1 — Printed circuit boards used to interconnect components of a single module as used in the amplifier circuits of video transmission equipment.

residual resin binder provides the necessary adhesion between the metallic particles and the base.

A plated wire board is produced by depositing a conductive pattern on an insulating material by chemical reduction, electroplating or a combination of both. There are several variations of this process which are used primarily where it is desired to continue the printed wiring through a hole or around a molded contour.

Embossed wire boards are produced by placing a copper foil over a laminated insulating board and depressing the conductor pattern into the board with a heated die. The unwanted portion of the foil is removed by a mechanical surface-abrading operation which leaves the conductors imbedded in the board.

Stamped wiring is similar to embossed wiring except that a "dinking die" is used; this simultaneously cuts the wiring pattern from the foil and places it on the surface of the insulating board. The conductors are usually made to adhere to the board in a secondary pressing operation.

In the transfer process, a mirror image of the printed wiring is formed on the surface of a carrier sheet by electroplating, etching or stamping. This image is transferred to the insulator by a subsequent pressing operation.

Etched wiring, which employs many of the techniques familiar to the graphic arts industry, is by far the most popular of the currently used methods. Most of the mechanics of this type of manufacturing are well established, and the copper-clad plastic raw materials had been under development by the laminating industry for several years prior to the full scale emergence of printed wiring. The process is adaptable to development type work where it is desirable to obtain small quantities of a large variety of circuit patterns within a short time. These are often used for laboratory development or study.

The photo-etch process originates with an enlarged layout of the conductor pattern. This drawing is called a "master" and is produced by applying precut strips of opaque, nonreflecting, pressure-sensitive tape onto a dimensionally stable Mylar film. The reverse side of this translucent film is printed with a grid coordinate system which is used as a guide by the draftsman for laying out the conductors in modular dimensions. Thus, each hole for a component mounting lead and each conductor is designated by cartesian coordinates.

The master is photographed and reduced to actual size with a precision copy camera. Any drafting errors on the master are thus minimized on the resulting negative, which may then be used to produce the conductor pattern on the circuit board. This negative is used to produce silk screens or offset printing plates which in turn are used to print the pattern on the board. The circuit board is a copper-clad laminate, generally one sixteenth of an inch thick, from which portions of copper are etched away to leave a pattern of conductive lines.

With the photo-engraving technique, a photosensitive "resist" (acid resistant lacquer or enamel) is applied to each copper surface from which the circuit is to be formed. The negative of the conductor pattern is placed over the sensitized surface and exposed to ultraviolet light which renders the conductor pattern insoluble in the developer. The areas protected from the light by the opaque portions of the negative remain soluble so that the resist is removed in the developer. The unprotected areas of copper are then etched away to leave a

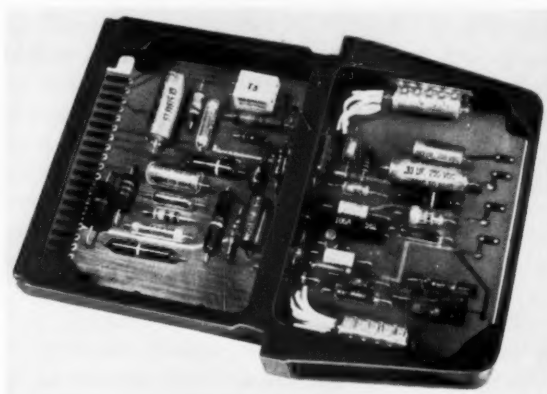

Fig. 2 — Printed circuit board used to interconnect the components of a single die-cast module unit.

pattern of the conductors on an insulating base.

After the resist material is removed and the board is cleaned, a thin coating of solder is applied to the conductors to provide protection during storage and to enhance solderability during subsequent assembling operations. This coating is applied by a "roller-coating" process wherein the fluxed board is passed through two rollers. One of these is tinned and partially immersed in molten solder; the other applies uniform pressure between the board and the tinned roller to insure that there is good wetting of the conductors.

Printed circuits of the sort described have greatly enhanced the primary objectives of military designers. These include such attributes as miniaturization, ease of maintenance, reliability and simplicity of manufacture. Their use generally leads directly to size reductions because the precise orientation and location of components and the elimination of wiring terminals reduces the waste space of

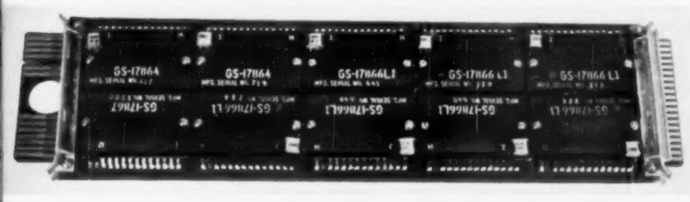

Fig. 3 — An example of printed wiring used to interconnect several sub-modules on a single board as used in a transistorized high-speed digital computer circuit.

point-to-point wiring. In addition, it is possible to incorporate small amounts of capacitance, inductance and shielding directly on the board and thus reduce the required amount of cabling and shielded wires. The size reduction is compounded in the over-all system by reducing the need for heavy structures to support the many heavy metal chassis and cables. This is illustrated in Figure 4 by a printed coaxial line on a circuit board for a transistor video amplifier.

Maintenance of electronic systems is improved by the use of printed-circuit unit assemblies which can be replaced much as electron tubes are replaced, and can be checked as functional units. Also, the time required for trouble shooting individual circuits is reduced because the circuit path is distinctly outlined in the printed-wiring pattern.

Reliability is improved in several ways. The designer is given greater control of the precise deployment of conductors in the manufactured units. This minimizes the possibilities of shorting and varying stray capacitances, and results in a more

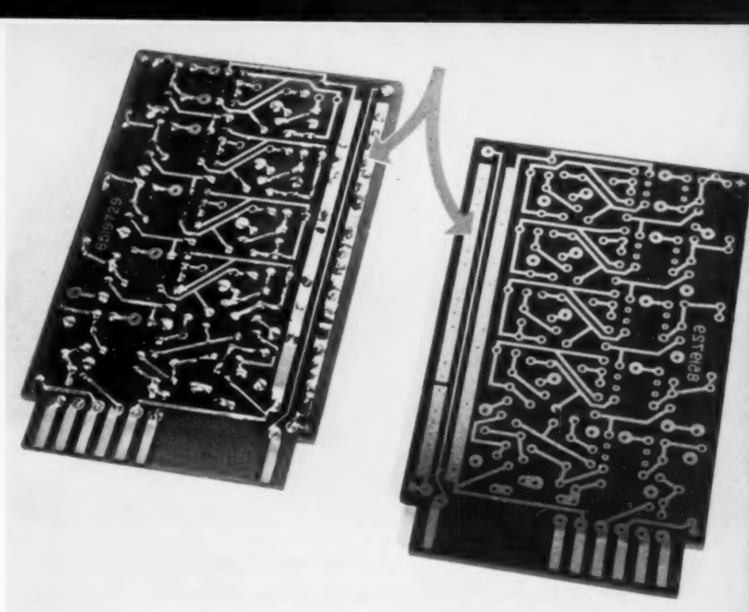

Fig. 4 — Coaxial line (arrows) produced by printed circuit techniques on transistorized video amplifier.

uniform product from which wiring errors have been virtually eliminated. In addition, the number of soldered connections can be greatly reduced, since it is possible to have any number of conductors emanating from a single point, and three or more components can be joined with a single continuous strip of copper.

The development of printed circuits has considerably advanced the art of automatic or mechanical assembly of electronic equipment. Unlike the conventional circuits of ten years ago with their maze of insulated wires, stand-offs and mounting terminals, hand wrapped and soldered joints and difficult assembly sequences, the printed-circuit board is readily adapted to large-quantity production and is ideally suited to mechanical insertion of components and mass soldering. Even in those instances where mechanical assembly is not feasible for economic reasons, the same design considerations result in units which are easier to assemble manually.

Printed circuits, however, are not a panacea. There are some disadvantages; special precautions must be taken, for example, to extend the field of application beyond that of low-power circuits. In this regard, systems designed to use printed circuits have a far greater proportion of insulating material than is normally encountered in conventionally wired equipment. This puts the burden of responsibility for satisfactory operation on the insulating materials, adhesives, conductor finishes and protective coatings associated with the printed-circuit board. Except for the metallic finish and some ceramic bases, most of the materials used are organic plastics. High temperature is by far the most ruinous environment for these materials — in fact,

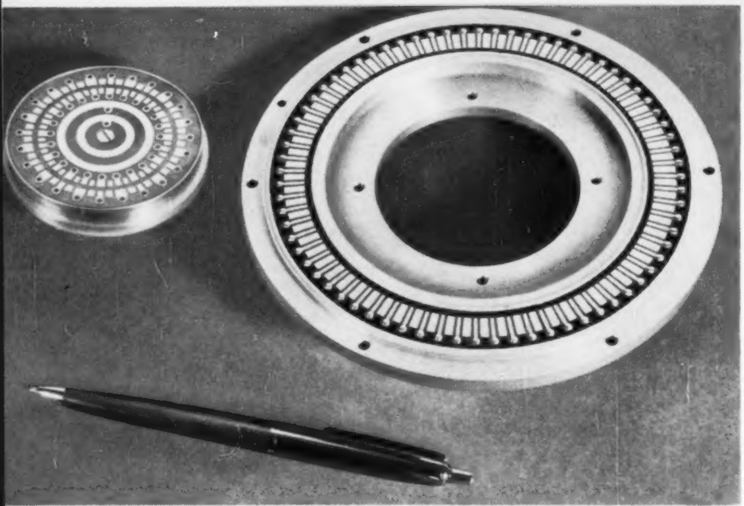

Fig. 5 — Rotary switches produced by printed circuit techniques; right, time sharing and left, zero set.

some of the present materials are combustible. Hence, special precautions must be taken to control heat dissipation.

Insulation resistance is also extremely important in the development and use of printed circuits. On a conventional plastic terminal board, the leakage path is governed by the spacing between terminals, since the effects of the strap wires are usually negligible. Conductors on a printed-circuit board, however, are in direct contact with the insulating base throughout their entire length. Thus, the leakage between two adjacent parallel conductors may be appreciable. It is, therefore, important to investigate this condition early in the design stage, and to employ materials which will insure proper performance under varying conditions of temperature and humidity.

Ionic contamination of the board during etching or plating, and staining of the surfaces by perspiration during handling, may result in a malfunction. This is due to corrosion or high leakage if the assembled unit is placed in a humid environment. Thus, it is necessary to cleanse the board thoroughly and to coat the surfaces with some type of insulating material. In addition, some plating solutions and improper soldering methods can destroy the bond and separate the printed conductor from the insulating base. Therefore, special soldering precautions must be exercised when replacing components during servicing.

The Laboratories has concentrated its efforts on fundamental studies of raw materials, the physical and electrical characteristics of printed wiring under various environments, and the exploration of methods for fabricating high-quality printed wiring. This was done to learn more about the capabilities of the materials and the processes so that realistic specifications could be established to insure a quality level consistent with the design intent of the Laboratories.

This program resulted in the development of a series of specifications, one of which contains procedures for testing the critical parameters of the base material or of the finished printed circuit. One test is for insulation resistance, another determines moisture sorption, a third gives a measure of adherence of the copper to the insulator and a fourth indicates the materials' resistance to blistering when subjected to soldering temperatures. Several specimens for each test are printed on one large panel in a manner which takes into account variations in properties due to orientation.

Contamination of the board due to processing has been virtually eliminated in a process called the Applique Method which was invented by the late E. E. Franz of the Laboratories. It is a transfer process wherein the raw materials consist of a composite sheet of aluminum and copper foil bonded together with a pressure-sensitive adhesive and a fully cured plastic laminate sheet. The exposed copper surface is treated with a partially cured thermosetting adhesive. Then the conductor pattern is cut from the copper foil by a dinking process in such a manner that the aluminum foil is not severed. The unwanted portions are stripped from the aluminum. This aluminum carrier is then placed on the surface of an insulating laminate, and a laminating press is used to bond the conductors firmly to the plastic sheet. The final operation is to strip off the aluminum carrier and clean the adhesive off the surface of the conductors.

The dinking die used in this process is prepared by photoengraving from a hard brass plate and then chrome plating the cutting edges to extend the life of the tool. Thus it is inexpensive and flexible to changes in circuitry. It is also adaptable to continuous processing which is necessary for any automated production system.

Allied with the problem of degradation of plastic-base printed circuits due to heat and long-term aging, the Laboratories is currently studying several processes for producing reliable inexpensive printed circuits on ceramic-base materials. One of these has been developed for producing a spiral inductor with conductors ten thousandths of an inch wide, spaced at ten thousandths of an inch. The requirements made it necessary to develop a process which did not rely on firing techniques and did not result in residual nonvolatile components.

Although these processes have been used primarily for printed wiring, they are by no means

limited to this application. There is an increasing number of applications in the design of switches, commutators, coding discs and electrical components. Complicated rotary and sliding switches can be produced by these means at lower cost because of the photoengraving technique. Also, the development of flush circuits, wherein the surface of the conductor and the insulator are in the same plane, has made possible a considerably smoother wiping surface for high-speed brushes. This reduces the hazard of brush bounce which results in erroneous switching.

An example of the application of the printed circuitry to components is an autotransformer which can be placed inside a cathode-ray tube as illustrated in the photograph on page 117. The construction, consisting of a series of flat printed inductors on ceramic discs, is capable of withstanding the high degassing temperatures and the cyclic temperatures of the tube during normal operation. Use of this autotransformer would remove the high potential connections from the exterior of the tube and thus reduce electric shock hazards.

The use of multiple-layer printed cables to reduce the size of a computer and to decrease its vunerability to shock and vibration is illustrated in Figure 3. Each module, representing a memory or logic function, is an encapsulated printed-wiring board with integral printed spring-contact fingers. These packages are mounted on a printed cablestick which consists of four layers of printed wiring and two printed connectors, one for test and the other for power and signal supply. Each stick is a plug-in unit which fits into a receptacle in the console and can be tested as a functional unit.

The impact of printed circuits on automation in the electronics industry is illustrated by the increasing number of mechanical assembly systems used to produce commercial and military electronic equipment. There will continue to be a large number of circuits which will not be economically feasible to assemble automatically. The mechanized assembling machines, however, will provide industry with a substantial standby force of robot assemblers, wiring hands and inspectors which can be called upon to meet sudden demands for a large amount of equipment. This would certainly be true in the case of military emergency when the defense services would require a tremendous volume of tactical and strategic electronic systems.

It is quite evident now that printed circuits have emerged from the laboratory development stage to become another in the series of new tools developed to promote the advance of electronics.

THE AUTHORS

N. Osifchin, a native of Phillipsburg, New Jersey, received his degree in Mechanical Engineering from Rutgers University in 1951 after serving two and one-half years in the Army. He joined Bell Laboratories that year as a member of the Nike Missile System group and was enrolled in the Laboratories Communications Development Training Program. In 1954 he transferred to the newly formed electromechanical development department, where he was in charge of a group concerned with the study and development of printed-circuit processes and applications. At present he is in charge of a group studying mechanical design problems associated with radars and missile-borne equipment. He is a recipient of the Lincoln Foundation Award and is a member of A.S.M.E. and Tau Beta Pi.

S. J. Stockfleth, a native of Bergen, Norway, came to the United States late in 1924 after receiving his B.S. in E.E. in Germany. Upon completing a graduate training course at the Westinghouse Corp., he joined the Manufacturing Development Department of the Western Electric Company at Hawthorne, where he developed multiple-coil winders and sealed-coil units, Mr. Stockfleth transferred to the Apparatus Development Department of Bell Laboratories in 1929, where he worked on the development of dials, multi-contact and crossbar switches on which he holds several patents. He was concerned with the mechanical design of military equipment during World War II, and after the war supervised a group responsible for mechanical design of the Nike System radars. Since 1953 he has been in charge of a subdepartment responsible for the mechanical design and development of military radar antennas, missile equipment, printed circuits, and the Whippany Mechanical Laboratory.

Organic Vapor and Relay Contacts

L. H. GERMER *Physical Research*

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Relay contacts in service sometimes erode much faster than laboratory life tests indicate they should. Often such erosion is due to "activation" — a subtle effect of organic vapors present in the operating environment. Activation has been studied for some years at Bell Laboratories, and the phenomenon is now quite well understood.

If you ask a telephone engineer, "what is the most important component in today's switching systems?", he will probably reply, "relays." The "business end" of these dependable electromechanical devices is the contact end. Relay contacts, since the advent of common-control switching systems, have probably earned the right to be singled out as the hardest workers in the telephone plant. A modern relay, for example, may have to operate more than 1,000 times in an hour.

In some cases, each contact operation may shorten the life of the relay because of "erosion" phenomena at work on the contacts. The amount of contact erosion – a direct measure of the amount by which the life of the relay is shortened – may vary by a factor greater than 100 with differing environmental conditions. Relay designers and research groups at Bell Laboratories have been aware of and have studied the causes and effects of erosion phenomena for many years. The effects of these phenomena are obvious – degradation of telephone service and increased relay maintenance. The causes of erosion are more subtle, however, and are only now becoming thoroughly understood.

The basic cause of erosion is electric arcs which occur when relay contacts are opened or closed, and a major factor influencing these arcs is a phenomenon called "activation." Activation is the contamination of the metal surface of a contact which gives rise to greater arcing (during either the "making" or "breaking" of an electrical circuit) than would occur at clean surfaces. This phenomenon is produced by repeated operation of a pair of current-carrying relay contacts in the presence of organic vapor. Basically, it is these organic vapors that cause increased arcing and increased contact erosion. The increase in arcing takes either of two forms: arcs when there would have been none

without the vapor, and arcs that last longer in the presence of vapor than they would in pure air.*

Organic vapors that produce activation come from many sources. Some of these are the plasticizer in the cellulose acetate of the relay coil winding, the phenol fiber in the relay structure, and the paint used on the walls of telephone central offices. Laboratory tests have shown that normally only noble-metal surfaces become "active" and that activation can be produced only by those organic compounds which contain rings of carbon atoms with at least one unsaturated bond between atoms in the ring. Benzene and benzene derivatives are examples of compounds with this molecular structure.

When a pair of palladium contacts is operated repeatedly in the presence of such an organic vapor, and the voltage across the contacts is displayed on an oscilloscope, the trace would look, in the beginning, as if no vapor were present. This non-arcing condition, as it appears on the oscilloscope screen, is shown in Figure 1(a). After continued operation, however, arcing can be observed. The arcing condition can be recognized by an irregular trace similar to the one shown in Figure 1(b). Even before any electrical effects are observable, however, incipient activation can be detected microscopically by the presence of black, sooty material on the contacts. This sooty substance is carbon, and the amount necessary for activation is extremely small – about 0.05 microgram.

Carbon is formed by the decomposition of organic molecules adsorbed on the contact surfaces. Arcs cause this decomposition, and the resulting carbon enhances the severity of the arcing, so that a vicious cycle of activation, arcs, carbon, increased arcing, and so on, can easily get started. The amount

* Record, *June*, 1954, *page* 226.

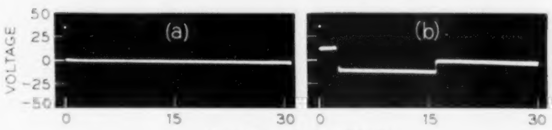


Fig. 1 — Oscilloscope trace of (a) non-arcing contacts, and (b) arcing at contacts after repeated operation in vapor. In both traces the circuit voltage was 35, indicated by the initial dots. The initial horizontal line in (b) represents the potential difference across the contacts during an arc lasting for 2 microseconds. This was followed by an open-circuit potential of —10 volts, lasting until final closure (zero potential) at about 16 microseconds.

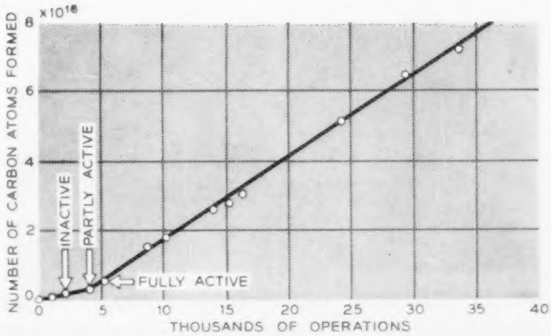


Fig. 2 — Plot of the rate of formation of carbon on relay contacts in the presence of organic vapor.

of carbon formed by one arc corresponds initially to about a single layer of organic molecules adsorbed on the portion of the contact covered by the arc. The rate of carbon formation later increases (Figure 2) to an amount corresponding to several monolayers of molecules, presumably because the carbon already present increases the active surface area of the relay contact.

In pure vapor, experiments have proved that the amount of carbon formed per contact operation is independent of the vapor pressure. When the vapor is simply part of the surrounding air, however, the situation is complicated by the presence of sufficient oxygen to burn some of the carbon already formed, and by the impedance offered by air to diffusion of organic molecules to the electrode surfaces. The rate of contact operation is a factor, too, in carbon formation. If the contacts are operated rapidly, less than a monolayer of activating molecules may be able to accumulate on the contact surfaces in the brief time the contacts are separated. These two factors – brief accumulation time and carbon burning – establish a minimum pressure of organic vapor below which the contacts of a relay do not become active.

The presence of carbon on contact surfaces changes both the character and intensity of the arcs. Consequently, the character and magnitude of the resulting erosion are also altered. We shall consider first the *character* of erosion with and without carbon, and then the effect of the presence of carbon on the *amount* of erosion.

Two distinct types of arcs occur between relay contacts. The type of arcing which occurs in any particular case is the dominant factor in determining the character of the contact erosion.* An "anode arc" vaporizes metal predominantly from the anode.

* Record, *June*, 1956, *page* 218.

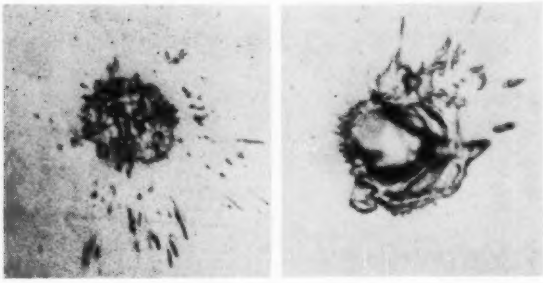


Fig. 3 — Photomicrograph (approximately 715 diameters) of marks made on cathode (left) and anode surfaces by a single arc of the anode type.

Here, the metal is vaporized by the heating due to electron bombardment, and a spatter of anode metal is left on the cathode (Figure 3). The second type, a "cathode arc", vaporizes metal from myriads of individual spots on the cathode. In this case, vaporization of the metal is caused by resistance heating, since almost the entire electron current of the arc flows through one of these tiny spots, vaporizing the metal with explosive suddenness. Cathodes arcs damage the anode very little, in many cases producing much less damage than is shown in Figure 4, except of course for the dispersed metal spattered over from the cathode.

The type of arc – anode or cathode – is determined by the electrode separation at which the arcs strike. At the beginning of an arc, a current made up of field-emission electrons is drawn from a single point on the cathode surface. If the electrode separation is small, a spot on the anode is raised to the melting point by electron bombardment before the current from the cathode becomes large enough to melt the emitting point. The resulting arc is called an anode arc. If, on the other hand, the separation is sufficiently large, the emitting point is melted first because the field-emission current spreads out considerably before it reaches the anode. In this case, the resulting arc is of the cathode type. The critical electrode separation that determines which sort of arc will occur is different for different metals, increasing with the increasing electrical conductivity of the metal. For palladium, the critical distance is about 0.5 micron, and for silver, three to four microns.

Both anode and cathode arcs transfer metal from one relay contact to the other when the contact surfaces are clean. An anode arc transfers metal from anode to cathode, and a cathode arc transfers metal from cathode to anode. After many successive arcs, a mound is built up on one electrode and a pit is eroded into the other. This deposit-erosion situation is entirely changed, however, by the presence of surface carbon. In the case of palladium contacts, surfaces that have carbon on them, so-called "active surfaces," transfer little or no metal, because the metal vaporized from one electrode is prevented from sticking to the other by loose carbon on its surface. The eroded metal can be recovered in the form of a loose, sooty powder mixed with carbon.

Carbon on electrode surfaces gives rise to another difference also. When carbon is present, each arc occurs at a new place – where carbon has been formed by preceding arcs, but not at the center of the immediately preceding arc where the arc has burned the carbon away. This continual relocation of the arcs results in uniform erosion of the electrode surfaces, with no formation of pits or mounds. At silver contacts, less carbon is often formed in the presence of organic vapors, and a great deal of the metal eroded from one contact may stick to the other, even in the active condition.

The change from pit-and-mound erosion to erosion which is uniform over the contact surface is not the only effect of the presence of carbon. A still more important effect of activation is the production of many more cathode arcs than anode arcs. Cathode arcs, as mentioned earlier, occur when an arc strikes at a contact separation greater than that giving rise to anode arcs. The presence of surface carbon increases the tendency toward arcing at wide separations, and this in turn results in a tendency for the dominant loss of metal to be from the cathode rather than from the anode.

Carbon on the electrode surfaces – resulting from activation – increases the contact separation at which arcing starts, because on an active surface

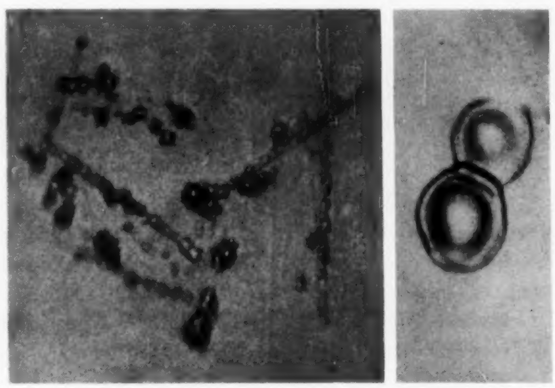


Fig. 4 — Appearance (900 diameters) of the cathode (left) and of the anode after a single cathode arc.

an arc strikes when the electric field generates electrostatic forces high enough to move the carbon particles. At the same time, the motion of these particles results in partial closing of the gap. In many cases, the electric field at which an arc strikes at carbonized surfaces is of the order of 0.5×10^6 volts per centimeter, which at fifty volts is a separation of one micron. This is considerably less than the critical distance of three to four microns which determines for silver electrodes whether an arc will be of the anode or cathode type.

Thus, activation does not, in most cases, alter the type of arc at silver surfaces when the striking potential is fifty volts. But it may alter the type of arc at higher voltages as, for example, at separating electrodes in an inductive circuit. For palladium contacts, on the other hand, the critical distance of 0.5 micron is so small that activation causes all arcs to be of the cathode type. Between *clean* palladium surfaces, however, most arcs at fifty volts are anode arcs. At silver surfaces then, the loss of metal is predominantly from the anode, whether the surfaces are clean or carbonized. At palladium surfaces (at 50 volts), loss is chiefly from the anode when the surfaces are clean, but from the cathode when they are active.

This situation is of course modified at high voltages. What will happen at any given voltage is predictable, however, if both the critical distance and the electrode separation at which an arc strikes are known. For example, about 350 volts is the minimum difference in potential at which the gases in the air between the two electrodes "break down" at atmospheric pressure. The distance at which voltages just above this value cause breakdown is about fifteen microns. This distance is so great that for voltages above 350, all arcs are cathode arcs for silver as well as for palladium, whether the surfaces are clean or active. These observations regarding the character of erosion resulting from arcs are presented in the table below.

To this point, we have been concerned with the effect of organic vapors on the character of erosion at contact surfaces. As brought out earlier, the magnitude of the erosion is affected as well as the character. In most cases, activation increases erosion by a large factor. This is due to two factors: the greater separation at which arcs can strike between active surfaces, and the lowering of the minimum current which can sustain an arc between such surfaces. The first of these effects – greater contact separation for active arcs – has been discussed above. This effect is also important in prolonging the length of time of arcing as contacts are pulled apart.

The second effect – the lowering of the "minimum arc current" – is most readily understood by considering an arc of the cathode type. For a cathode arc, the minimum arc current is the lowest current which will promptly explode a point on the cathode through which the current flows. A carbon particle on the cathode has relatively high electrical resistivity as well as poor thermal contact to the supporting metal. The lowest current which can explode it, therefore, is much less than the minimum current required to explode a spot on clean cathode metal. Specifically, experiments have shown that the minimum arc current for a clean metal surface may be as high as one ampere but for a carbonized surface it may be as low as 0.03 ampere.

It is possibly this feature of activation – the lowering of the minimum arc current – that makes contact activation most objectionable. At contacts with a minimum arc current that is low, an arc can often last for a much longer time than it would if the minimum arc current were higher. This longer arcing time results in greatly increased erosion.

To prevent arcing at relay contacts, it is common

TABLE: TYPES AND CHARACTERISTICS OF EROSION

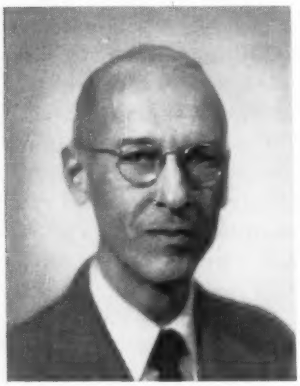
Anode Type of Arc	Cathode Type of Arc	Character of Erosion: Below Air Breakdown Voltage		Above Air Breakdown Voltage	
		Cathode	*Anode*	*Cathode*	*Anode*
Inactive					
Pd, Ag		Gain (mound)	Loss (pit)	—	—
	Pd	Loss (pit)	Gain (mound)	Loss (pit)	Gain (mound)
	Ag	—	—	Loss (pit)	Gain (mound)
Active					
Ag only		No change*	Loss (smooth)*	—	—
	Pd	Loss (smooth)	No change	Loss (smooth)	No change
	Ag	—	—	Loss (smooth)	No change

* At high vapor pressure. At low vapor pressures there may be an anode pit, with much of the eroded metal sticking to the cathode in the form of a mound.

practice in telephone circuits to install a protective network consisting of a capacitor in series with a resistor across the contacts, or across the inductive load. Such a circuit can be effective only when the minimum arc current is higher than the circuit current. Thus, it turns out that active contacts in ½-ampere circuits, fairly common in the telephone plant, cannot be protected against arcing. Furthermore, activation is damaging even in low-current circuits. Here, intermittent arcing can occur due to the discharge of local capacitance. When contacts are active, the repeated discharge of local capacitance may produce erosion that is almost as severe as the erosion from a sustained arc in a circuit that is normally considered as carrying a high current.

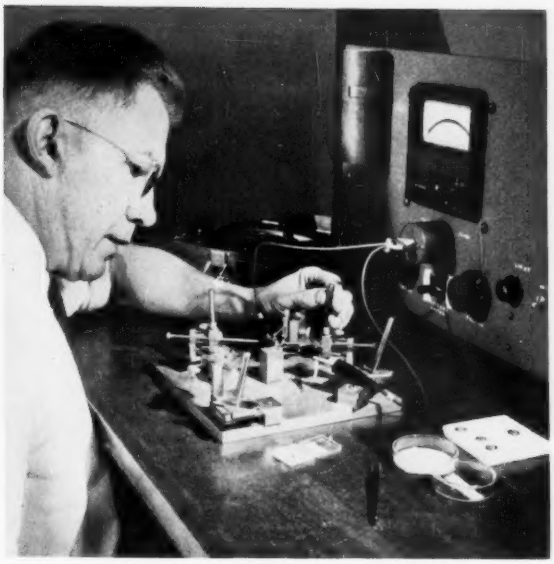
Although both the causes and effects of activation are now well understood, the phenomenon nevertheless sometimes presents problems in relay design. Activation can be reduced both by using stable materials which are not sources of organic vapors, and by adequate ventilation. The cost and other consequences of any possible change are often an important consideration, and what to do in any particular case is not always at once clear.

THE AUTHORS



L. H. Germer, a native of Chicago, received the A.B. degree from Cornell University in 1917, and the M.A. and Ph.D. degrees from Columbia University in 1922 and 1927, respectively. In 1917, he joined the Engineering Department of the Western Electric Company and has been at Western Electric and Bell Laboratories since that time, except for a period from 1917 to 1919 when he served in the U. S. Air Force. Mr. Germer's work has been in various fields of physical research including thermionics, electron diffraction, surface phenomena and the physics of electrical contacts. He is the author of over seventy scientific papers on these subjects.

J. L. Smith, a native of Morristown, N. J., joined the Laboratories in 1941 as a messenger. After serving three years in the U. S. Navy, he returned to the Physical Research Department where he worked on problems concerned with relay contact erosion. From 1946 to 1956 Mr. Smith attended the evening division of the Newark College of Engineering, receiving the B.S. in E.E. degree. In 1956 he transferred to the Switching Development Department where he is currently engaged in the design of switching networks using solid-state devices. Mr. Smith is a member of Tau Beta Pi.



A major difficulty in the development of high-frequency transistors has been the formation of reliable electrical contacts between extremely fine wires and minute areas of semiconductor crystals. At Bell Laboratories, a promising solution to this problem has been found — a technique known as thermo-compression bonding.

H. CHRISTENSEN *Transistor Development*

Electrical Contact with Thermo-Compression Bonds

For the past several years there has been a strong trend toward miniaturized electronic devices. In part, this trend is attributable to the great economies possible with small, compact equipment. The electronic telephone switching systems of the future, for example, are expected to be so much less bulky than present equipment that they should result in considerable savings to the Bell System in floor space and sizes of central offices.

There is, however, another important reason for miniaturization of electronic circuits, stimulated in large measure by the invention at Bell Laboratories of the transistor. Because of its inherently small size and lower power requirements, the transistor permits other components in a circuit to be reduced proportionately in size. Further, there has been considerable emphasis on high-frequency operation for greater bandwidth of communication systems. Since the elements of electronic devices in general become smaller at the higher frequencies, this means that the already small transistor structure has progressively become even smaller.

When structures are to be fabricated to virtually microscopic dimensions, many complications appear, not the least of which is the sheer mechanical difficulty of working with tiny parts. In addition, semiconductors are frequently sensitive to mechanical disturbances and to minute traces of unwanted chemical contamination – a consideration that imposes strict limitations on methods of fabrication.

In many such cases, an outstanding mechanical difficulty is that of securing a bond between very thin electrical conductors and the semiconductor. The bond must be accurately positioned in a small area; it must have the least possible effect on the electrical characteristics of the semiconductor; and

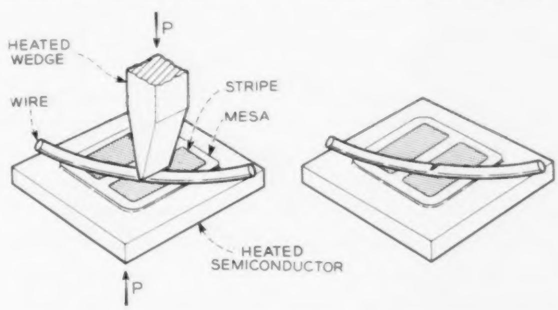


Fig. 1 — Representation of the bonding process. Heat and pressure produce the bond with very little contamination of the semiconductor material.

it must be mechanically strong and reliable. This difficulty is overcome to a large degree by the application of a new technique of joining solids called thermo-compression bonding. The technique is the result of fundamental research on the adhesion of solids* performed jointly by O. L. Anderson of the Research Department and the author.

Current practice of attaching leads to semiconductors involves alloying or soldering. These are

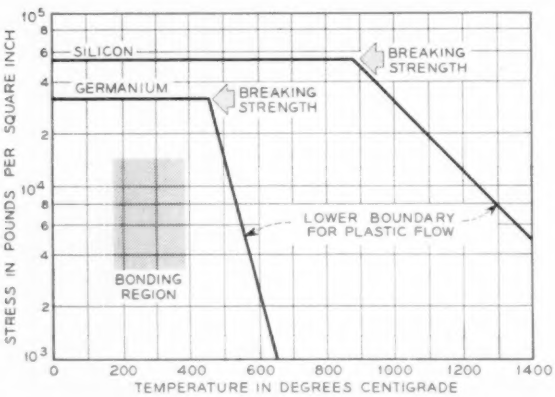


Fig. 2 — Tensile-strength curves for brittle fracture (horizontal lines) and plastic yield (steep lines) for germanium and silicon. Bonding region for experiments (shaded area) is well inside these limits.

objectionable because both involve a liquid phase, which gives rise to problems of alloy depth control, wetting and chemical contamination. The bonding process described here does not involve liquid phase formation and hence avoids these problems. As shown in functional schematic form in Figure 1, it merely involves the application of heat and pressure to the members being bonded. When these are applied for a few seconds, adhesion occurs. The two main advantages of such a bond are its simplicity of formation and its freedom from chemical contamination.

A 5000 to 10,000 psi pressure, 200 to 300°C temperature range, and a 5-second time interval are appropriate conditions for formation of a bond between a gold wire and a block of germanium. The upper range of temperature and pressure are used where the wire is hardened by cold working or by the addition of "doping" (impurity) metals like aluminum or arsenic from the third and fifth columns of the periodic table. Where metal-to-metal bonds are to be made — for example in bonding leads to a transistor electrode — the time for bonding can be reduced somewhat. Some cleaning of the surface may be necessary prior to the bonding operation. Gold wire is sometimes degreased and annealed, but alloyed transistor emitter and base electrodes, discussed later, are satisfactorily clean as they come from the alloying process.

The most important issue involved in application of thermo-compression bonds to semiconductors is the question of possible mechanical damage to the semiconductor. Figure 2 relates temperature and pressure of bonding to brittle fracture and plastic stress of silicon and germanium. In this illustration, the shaded area represents the region of successful bonding; it encompasses all the pressure and temperature conditions used to date to bond gold, silver, aluminum and various alloys of these materials to silicon and germanium.

By noting the distance of the bonding region from the curve for germanium, it is apparent that sufficient margins exist for both temperature and breaking strength. The curve for the onset of plastic flow in the crystal is at least 100°C from the bonding region, and along the vertical axis, breaking stress is seen to be at least double the highest stress used for bonding. It is also apparent in Figure 2 that silicon is even better in these respects. Actually, since no compression data for silicon and germanium are available, tensile-strength values are plotted in Figure 2, which means that the safety factors are still higher. Several thermo-compression bond areas have been studied, and no increase in density of dislocations associated with plastic flow or cracking has been found.

An early experimental application of thermo-com-

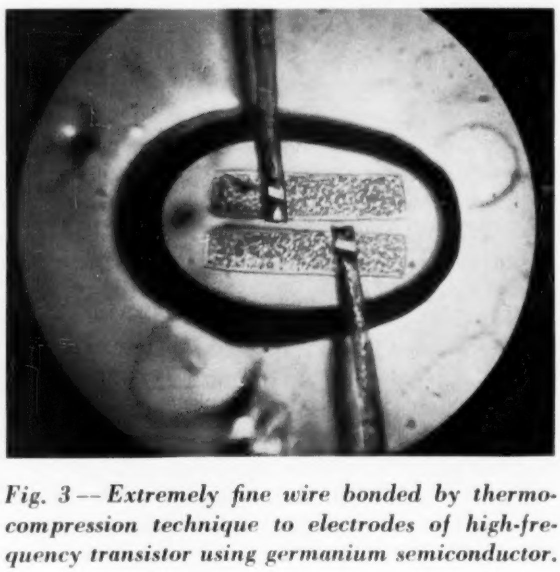


Fig. 3 — Extremely fine wire bonded by thermo-compression technique to electrodes of high-frequency transistor using germanium semiconductor.

* RECORD, *November*, 1957, *page* 401.

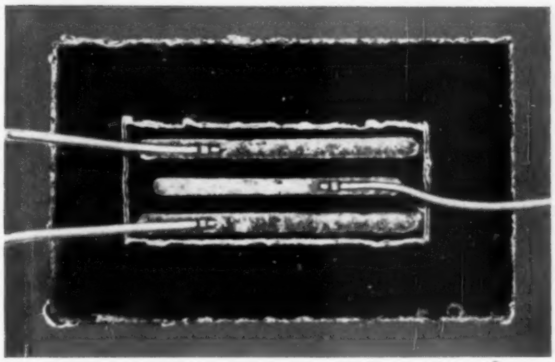


Fig. 4 — Gold leads thermo-compression bonded to silicon in a power transistor. Bond passes 300 milliamperes of continuous current.

pression bonding was the attachment of lead wires to evaporated and alloyed gold and aluminum electrodes of diffused-base transistors. Figure 3 shows an example of bonded leads on a high-frequency germanium transistor having very closely spaced elements. The dark stripe is the aluminum alloy emitter; it is about 0.006 inch by 0.001 inch. The bright stripe is the alloyed gold base electrode. The 0.0004-inch diameter gold lead wire is smaller than can be made by direct drawing. It was formed by first drawing down a silver-clad gold wire and then dissolving away the silver. The resistance of the bonded contact, after correction is made for the lead resistance, is about 0.01 ohm. This is as expected for a metallic contact without intervening resistive skin. When the bonded lead is forcefully pulled away from the electrode, either the lead wire breaks or a bit of germanium is extracted with the wire, showing that the bond is stronger than the weaker of the lead or germanium.

Figure 4 shows the bonded gold leads of a silicon power transistor. The wire is 0.002 inch in diameter, and the bond passes up to 300 milliamperes continuously without deterioration or failure. All three electrodes shown here are of a gold-silicon alloy. This photograph illustrates the fact that the bond is also satisfactory for large power requirements. In this case, two base stripes are used to reduce base resistance. In certain variations of the development of this transistor, more than one lead could be attached to the electrode. Such features and many others make thermo-compression bonding attractive from the point of view of versatility of design.

The electrical characteristic of a metal-to-germanium thermo-compression bond is of considerable interest, both for potential application in device technology and also for the investigation of a metal-to-semiconductor interface. When carefully formed, bonds of this sort give either rectifying or nonrectifying (ohmic) contacts in accordance with surface doping produced by the bonding wire.

Figure 5 illustrates the conditions under which rectification is produced in a thermo-compression bonded contact of an aluminum wire to a block of n-type germanium. For the germanium under this type of bond, curve A shows theoretical values of spreading resistance—the resistance introduced by the crowding of flow lines of electricity in the germanium as they come to the confining area under the bond. Curve A is to be compared with curve B, which represents actual data obtained from a contact bonded in air. As can be seen, this curve is intermediate to curve D. Data for curve D were obtained after bond B was heated to a temperature slightly above the aluminum-germanium eutectic — the lowest temperature that gives a liquid phase when Ge and Al are heated (425°C). Curve C shows the effect of using a hydrogen atmosphere for bonding instead of air. In this case, we have a bond that forms a rectifier that will saturate. The difference between curves B and C is accounted for by the contamination introduced by the air ambient. Trace contamination on either the wire or the germanium surface probably accounts for the difference between curves C and D seen in Figure 5.

One distinct possibility for application of this type of bond is the process illustrated by curve D. At the expense of introducing a liquid-phase eutectic into the process, we can form both an electrode and a lead in one operation. A measure of control

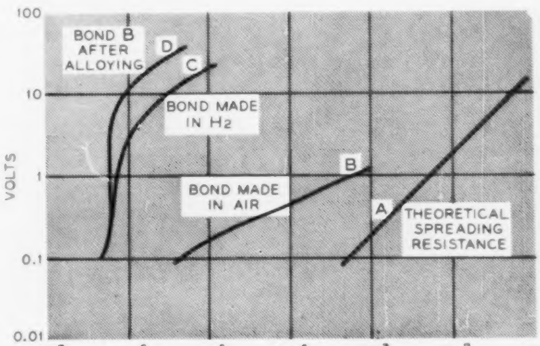


Fig. 5 — Theoretical "spreading resistance" (A) compared to actual voltage-vs-current characteristic curves for bonds made by the various methods.

of alloy depth is obtainable in this case because the liquid-phase eutectic forms at one or two degrees above the eutectic temperature, and wetting occurs over the bonded area. Another feature of alloy depth control is the fact that the lead wire can be of eutectic composition, so that it does not require much germanium to go into solution to form the liquid phase.

Thermo-compression bonding is thus seen to be a significant advance in semiconductor technology. By the application of heat and pressure, the bond can be formed either with or without formation of the liquid phase, as desired. The procedure may be used to improve wetting and control of depth in the alloying process. When a bond is made to a semiconductor, the contact may be either ohmic or rectifying, depending upon the doping of the bonding wire and of the semiconductor. The technique is presently being applied experimentally in transistor fabrication at Bell Laboratories.

THE AUTHOR

H. Christensen, a native of Manti, Utah, received the B.S. degree in physics from Brigham Young University in 1930 and the M.A. degree, also in physics, from Columbia University in 1935. He has been a member of the technical staff of Bell Laboratories since 1930, when his first assignment was in the Submarine Cable Research Department. In 1937 he began semiconductor material research work, which he later used in the development of the thermistor bolometer. From the beginning of World War II until 1950, Mr. Christensen worked on NDRC and U. S. Navy contracts, and subsequently was engaged in investigation of germanium material processing and surface phenomena. Since 1954 he has been engaged in advanced development of diffused-base transistors. He is a member of the American Physical Society and of the A.I.E.E.

"BMEWS": Major Communication Project Announced

The Western Electric Company disclosed on February 19 the receipt of a prime letter contract from the U. S. Air Force for an important communications project in connection with a Ballistic Missile Early Warning System, and said there would be "substantial participation" by Bell Laboratories in the project. The text is as follows:

"A prime letter contract has been received from the U. S. Air Force authorizing the Western Electric Company to proceed with the initial phases of a communications project of major dimension in connection with a Ballistic Missile Early Warning System (BMEWS).

"Western Electric's responsibilities involve improving and augmenting communications in northern areas which will serve the new warning system and which will be coordinated with other military requirements. Work on the new project is already underway.

"The Radio Corporation of America is prime contractor for the remote detection installations of BMEWS as well as certain work at terminals in the United States. Although RCA and Western Electric have separate prime contracts, close cooperation will be required between the two companies on those facilities concerned with the BMEWS project.

"At Western Electric, the work will be handled by the Defense Projects Division where prior experience with the DEW and White Alice systems is expected to be of great value. There will be substantial participation by the Laboratories in technical areas, as well as the assistance of agencies responsible for interconnecting commercial circuits.

"The contract covers responsibility for design, installation and testing of new or augmented routes outside of commercial areas and for overall communication system tests. Responsibility for construction of buildings and associated facilities has not been announced. The project will require standard Bell System equipment as well as some of new and special design. Western Electric will manufacture the normally supplied Bell System items as well as certain of the new designs the Company's plants may be especially qualified to furnish. It is expected that a substantial portion will be subcontracted to qualified manufacturers.

"The total personnel required is not known at this time but it is expected that the present staff on the DEW and White Alice projects will be increased by personnel from other Bell System companies and Western Electric as the need for particular skills develops."

A. T. & T. Annual Report Cites Gains in 1957

—Tells of Bell Laboratories Research

Bell System earnings were $13 a share of American Telephone and Telegraph Company stock in 1957, President Frederick R. Kappel said in the company's annual report, released February 18.

The earnings were based on the average of 63,811,000 shares outstanding–6,388,000 more than in 1956, when net income per average share equalled $13.16. Bell System earnings on total capital were 6.7 per cent, compared with 6.8 per cent in 1956.

The Bell System spent more than $2.5 billion in 1957 to enlarge and modernize telephone plant. Most of the new capital obtained last year was through the sale of bonds. These totaled just over a billion dollars. The average interest cost, Mr. Kappel pointed out, was nearly 4¾ per cent – the highest in many years. Part of the money to expand and improve telephone service in 1958 will come from an issue of $718 million of debentures convertible into stock. Share owners may buy one $100 debenture for each nine shares of stock held.

The A.T.&T. report, mailed to more than 1,600,000 share owners, cited many gains in service. It stated, for example, that in 1957 the Bell System added some 2,815,000 telephones, bringing the total operated by the System to 52,250,000. Long distance conversations rose more than 7 per cent over 1956. Long distance service was the fastest ever. The average speed of connection was only 72 seconds. The Bell System changed a million more telephones to dial service. Today 92 per cent of Bell telephones are dial operated. Also, some five million customers today can use "DDD" – direct distance dialing – to as many as 30 million other telephones from coast to coast. Another 10 million customers can dial nearby cities and towns.

The report also cited gains in undersea cable service. Since the opening of the new telephone cable between the U. S. mainland and Hawaii last October, calls to and from the island territory have increased about 30 per cent. The first telephone cable across the Atlantic, opened in 1956, is now so heavily used that work has already begun on a second cable which is expected to be ready in 1959.

Research and Manufacture

Underlying all the progress, the A.T.&T. report noted, are research at Bell Telephone Laboratories and manufacture of equipment by Western Electric. In addition, both organizations continue to work on guided missile systems and other vital defense projects.

Bell Telephone Laboratories, Mr. Kappel said, "is one of the largest research organizations in industry. One reason is simply that there is so much work to be done. Also, big size in itself is a distinct asset. To make significant scientific discovery we

W. L. Hawkins of the Chemical Research Department conducting oxidation tests on polyethylene to determine effectiveness of antioxidants.

C. D. Thurmond and Mrs. E. A. Wood discussing structure of silicon as part of basic research into properties of semiconductors.

need the best scientific minds. Those minds usually want the stimulus of association with others of like caliber, in a well-rounded scientific community that has pre-eminent standing. This we have in Bell Laboratories.

"There for many years the attack on communication problems has begun with basic research – the search for new understanding and knowledge of nature. This has made possible long distance service; the multiplication of talking paths over the same physical conductors; the development of radio relay systems; the creation of modern dial switching systems; and many other developments. In fact, the entire telephone network of today is built on the knowledge which basic research has supplied.

"The transistor, invented at Bell Laboratories about ten years ago, is now finding many communication uses: to route long distance calls automatically; to provide rural telephone circuits; to send data at high speeds; to produce the 'ringing signal' in telephones; to amplify sound in other telephones for people who have difficulty in hearing. . . . These are examples. Also, development work continues on the new electronic switching system in which transistors play a vital part. This is a major undertaking. We are confident it will make possible many new conveniences and improvements in service.

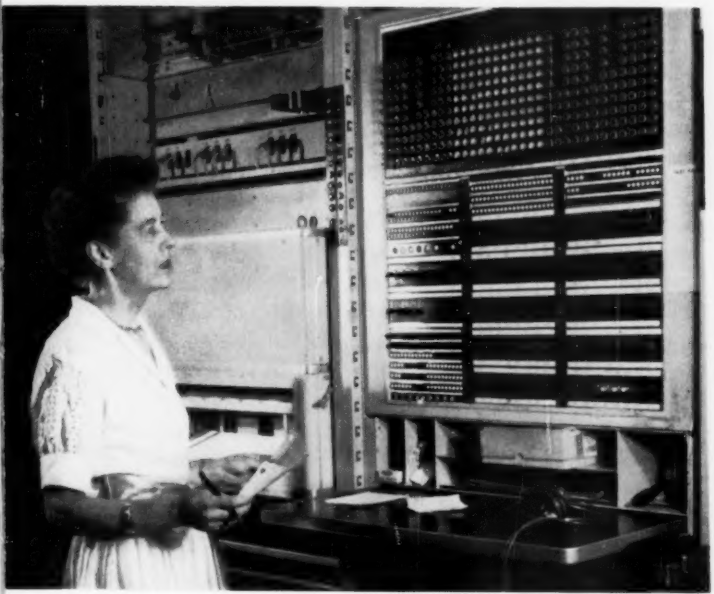
"Meanwhile basic research goes on. Bell System scientists today are studying the effects of nuclear radiation on crystals and plastics. They have found new ways to join materials together–to bond them so that they may be used in ways previously impossible. They are studying how to send huge quantities of information over long distances through hollow 'waveguides.' They have demonstrated an entirely new microwave amplifier – a small crystal in which, at a temperature near absolute zero, the spin of electrons in the atoms provides the amplifying action. Such a device promises to detect far weaker signals than could ever be detected before – even reflections from small objects in outer space."

Among the new developments now under way at Bell Laboratories, Mr. Kappel said, is TASI – short for "Time Assignment Speech Interpolation." TASI is expected to increase greatly the capacity of telephone circuits such as those in the oceanic cables.

"Today twin ocean cables (one for each direction of talking) can carry 36 conversations at once," Mr. Kappel said. "What we look forward to is that TASI may as much as double this capacity. This it will do by taking advantage of the times when people are listening or pausing. The voice channels they leave temporarily unused will be automatically assigned to other talkers; and when a listener starts to talk he will instantly have the use of a channel which another person has left idle."

The A.T.&T. president also commented on the growing use of microwave radio: "In fact, use of radio is sure to be more and more important in enabling us to provide the best and most economical service in years to come. We have therefore asked the Federal Communications Commission to increase the number of microwave frequencies allocated to communication companies.

"The number of frequencies is limited, and a policy assuring their orderly assignment to companies serving the general public will allow far more efficient use of the radio spectrum than could result from indiscriminate licensing for private operation. Moreover, such a policy is essential to permit expansion of the communication network in ways that will best serve the nation's defense."



The Study of Performance in Switching Systems

CHARLOTTE HAMILTON
Systems Engineering III

Because dependable switching apparatus is of basic importance to quality of telephone service, Bell Laboratories engineers conduct extensive reliability studies. Their primary sources of data are actual performance records — trouble tickets from central offices and other types of special information.

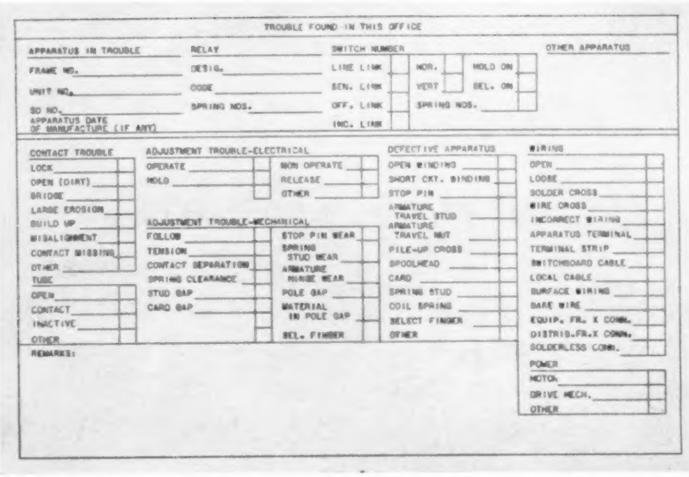
Modern electromagnetic switching offices contain a complex array of apparatus wired into circuits to form a working unit. A single call established by this equipment may require the operation of a thousand or more relays. Many thousands of calls are handled daily by an office without incident, but troubles do inevitably occur.

Troubles in central-office switching equipment are, in general, apparatus or wiring troubles rather than circuit difficulties. They include items such as adjustment and contact troubles, defective parts, and wiring defects. Whatever the cause, central-office troubles are of concern to Laboratories engineers because, fundamentally, good design must take into consideration the effects of service use and environment, and the reliability of the commercially-manufactured and installed product.

Knowledge of apparatus performance is obtained from two sources: laboratory tests under simulated field conditions and actual field data. Of these two, the laboratory tests are usually conducted for specific reasons. They are valuable both because they permit early evaluation of design and because they can be so arranged that troubles occurring during laboratory testing can be readily located. For example, the new wire-spring relay, during development and early production, was subjected to many laboratory tests of adjustment stability, contact performance, and other characteristics. These tests evaluated the effect on performance of new features such as lowered contact pressure, smaller contacts, gold-overlay contacts, and the individual relay covers.

All the varied conditions of circuit usage, traffic load, and environment met in the field, however, cannot be duplicated in the laboratory. To provide performance data under actual operating conditions, the Laboratories conducts frequent field studies using detailed records of the troubles experienced in central offices. These studies may be limited to specific objectives or types of equipment, or they may be "system studies" in which complete trouble records are obtained from a group of operating offices representing a particular system. An advantage of systems studies is that they are not confined to any one portion of the switching office. Thus they may direct attention to unforeseen conditions in any element of the switching equipment. Systems studies also provide a larger sample than most laboratory tests and special studies.

Systems studies are based primarily on definitely located troubles whose cause has been determined.



TROUBLE FOUND IN THIS OFFICE

APPARATUS IN TROUBLE
FRAME NO.
UNIT NO.
SD NO.
APPARATUS DATE OF MANUFACTURE (IF ANY)

RELAY
DESIG.
CODE
SPRING NOS.

SWITCH NUMBER
LINE LINK
SEN. LINK
OFF. LINK
INC. LINK
HOR.
VERT
SPRING NOS.
HOLD ON
SEL. ON

OTHER APPARATUS

CONTACT TROUBLE
LOCK
OPEN (DIRT)
BRIDGE
LARGE EROSION
BUILD UP
MISALIGNMENT
CONTACT MISSING
OTHER

TUBE
OPEN
CONTACT
INACTIVE
OTHER

ADJUSTMENT TROUBLE-ELECTRICAL
OPERATE
HOLD
NON OPERATE
RELEASE
OTHER

ADJUSTMENT TROUBLE-MECHANICAL
FOLLOW
TENSION
CONTACT SEPARATION
SPRING CLEARANCE
STUD GAP
CARD GAP
STOP PIN WEAR
SPRING STUD WEAR
ARMATURE HINGE WEAR
POLE GAP
MATERIAL IN POLE GAP
SEL. FINGER

DEFECTIVE APPARATUS
OPEN WINDING
SHORT CKT. WINDING
STOP PIN
ARMATURE TRAVEL STUD
ARMATURE TRAVEL NUT
PILE-UP CROSS
SPOOLHEAD
CARD
SPRING STUD
COIL SPRING
SELECT FINGER
OTHER

WIRING
OPEN
LOOSE
SOLDER CROSS
WIRE CROSS
INCORRECT WIRING
APPARATUS TERMINAL
TERMINAL STRIP
SWITCHBOARD CABLE
LOCAL CABLE
SURFACE WIRING
BARE WIRE
EQUIP. FR. X CONN.
DISTRIB.FR.X CONN.
SOLDERLESS CONN.

POWER
MOTOR
DRIVE MECH.
OTHER

REMARKS:

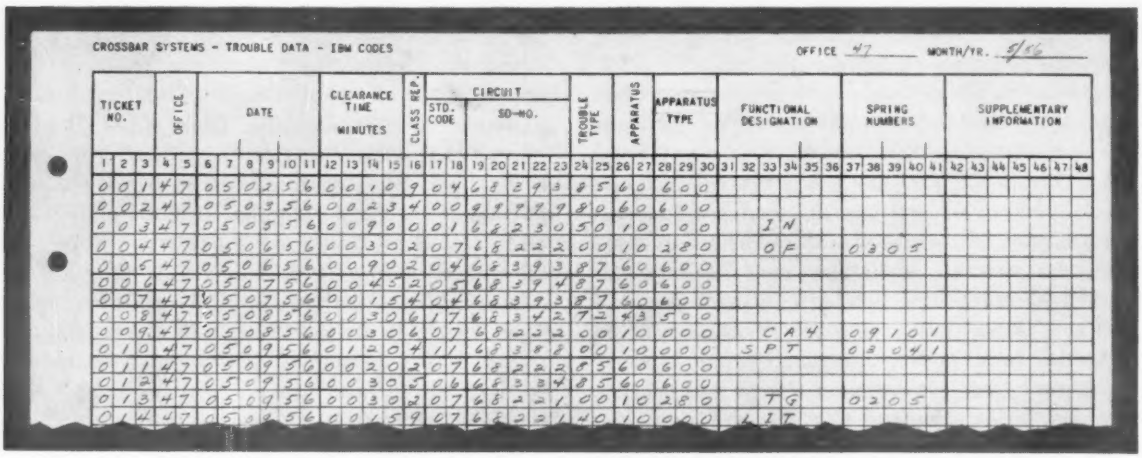
Fig. 1 — Data from the back of standard trouble ticket are the major source of information for the studies of telephone switching systems.

These are known as "found troubles." In common-control switching systems, found troubles are estimated to be less than 10 per cent of total troubles occurring in an average central office. A recent study of No. 1 crossbar data indicated that, for every trouble found, about twelve troubles are "not found." (A not-found trouble is one that cannot be specifically identified with a cause, either because it cleared during tracing attempts, or because tracing was unsuccessful or not attempted.) Of the twelve not-found troubles, an attempt at trouble location is made, on the average, in only about three cases.

This low percentage of troubles traced and found can be better understood by considering the nature of switching equipment and the trouble-location procedures. Many troubles are not service-affecting, since the "second-trial" feature of crossbar systems usually results in a valid connection. Both first- and second-trial troubles do, however, automatically leave a record of the progress of the call up to the time the trouble occurred. Troubles are traced either from these records or from other indications such as alarms, stuck senders, routine test failures, or reports from customers or traffic employees. Trouble indications include many cases of repeat or multiple registrations from a single trouble. Also, many of these indications are caused by conditions in the outside plant or in connecting offices.

Economically, it is undesirable to use maintenance time for tracing all indications of trouble, because of the transient or intermittent nature of many of them, and because the indications often cannot be successfully analyzed. Troubles not traced or not found probably include items such as transient dirty contacts, partial loss or adjustment, or intermittent opens in windings or at wiring connections. Found troubles, however, can be assumed to include the more persistent troubles and those of an urgent nature from the standpoint of service. Actually, these are the only source of the specific information required.

There are several considerations in planning systems performance studies. First, results representative of the system are sought. To this end, all offices that qualify for study purposes are listed in groups, based mainly on geographical location and equal numbers of offices are selected at random from each group for participation in the study. The total number of offices selected is sufficient for a



CROSSBAR SYSTEMS - TROUBLE DATA - IBM CODES

OFFICE 47 MONTH/YR. 5/56

TICKET NO. (1–3)	OFFICE (4–5)	DATE (6–11)	CLEARANCE TIME MINUTES (12–15)	CLASS REP. (16)	CIRCUIT STD. CODE (17–18)	CIRCUIT SD-NO. (19–23)	TROUBLE TYPE (24–25)	APPARATUS (26–27)	APPARATUS TYPE (28–30)	FUNCTIONAL DESIGNATION (31–36)	SPRING NUMBERS (37–41)	SUPPLEMENTARY INFORMATION (42–48)
001	47	050256	0010	9	04	68293	85	60	600			
002	47	050356	0023	4	00	99999	80	60	600			
003	47	050556	0090	0	01	68230	50	10	000	IN		
004	47	050656	0030	2	07	68222	00	10	280	OF	0205	
005	47	050656	0090	2	04	68393	87	60	600			
006	47	050756	0045	2	05	68394	87	60	600			
007	47	050756	0015	4	04	68393	87	60	600			
008	47	050856	0030	6	17	68342	72	43	500			
009	47	050856	0030	6	07	68222	00	10	000	CA4	09101	
010	47	050956	0120	4	11	68388	00	10	000	SPT	03041	
011	47	050956	0020	2	07	68222	85	60	600			
012	47	050956	0030	5	06	68334	85	60	600			
013	47	050956	0030	2	07	68221	00	10	280	TG	0205	
014	47	050956	0015	9	07	68221	40	10	000	LIT		

Fig. 2 — Statistical information coded for transfer to punched cards.

statistically adequate sample. Offices chosen by this method, known as "stratification," represent a variety of Operating Companies and areas, and satisfactorily provide a cross section of the system with respect to environment, local maintenance practices, traffic loads, and similar factors.

A second consideration in planning the studies is the importance of obtaining, in addition to complete trouble records, certain supplementary information that will permit proper interpretation and presentation of the data. Requested from each office is a count of each major type of equipment and each type of relay. This provides a meaningful basis for prorating trouble data. In addition, traffic data are obtained to indicate the call load handled and to prorate trouble in terms of usage. Other supplementary information concerns the environment in which the switching equipment operates. It includes principally a record of any special activities, such as the Western Electric Company installation work occurring during the study, and information such as the type of ventilating equipment used in the switchroom and whether or not the humidity is controlled.

A third consideration is the need to obtain accurate and complete data. Basically this depends on cooperation of the field personnel involved and on their understanding of the aims and requirements of the study. Careful thought is given, therefore, to the form in which the data is requested as well as other details of initiating the study.

Found-trouble data are obtained from trouble tickets which are the original records made by the switchmen. Because trouble tickets are made out for local use only, they may be incomplete or even misleading from the analyist's viewpoint because of varying use of terms by different personnel or areas. To insure maximum accuracy and completeness of trouble reports and of other data, the Laboratories prepares a folder with special instructions and definitions for the use of the personnel reporting the data. The definitions apply primarily to the back of the standard trouble ticket (Figure 1), which was designed mainly for study purposes and provides more information than is generally required for central office administration.

During the planning stage of the study, Laboratories personnel visit some of the selected offices. Discussions with Operating Company personnel on the proposed forms and instructions and on the type of data required have proved very helpful, and have served to acquaint these people with the objectives of the study.

In a typical systems study, five to ten thousand trouble tickets may be received in the course of a year. Full use of this information requires it to be summarized in several ways, and portions to be extracted for detailed analysis. For instance, the analysis must show the troubles experienced in different types of apparatus and circuits and the indications that were effective in revealing these troubles. Also, it may be necessary to examine details, so that factors such as the functional use of the apparatus at fault may be considered in the analysis.

Through use of punched cards the data are put into a form that will permit this flexibility in summarizing and analyzing. The information obtained from each trouble ticket is translated into codes which are, in turn, punched on the cards. Each card represents one trouble. A coding system requiring a minimum of translation has been developed for this purpose. Where possible it uses standard apparatus codes or direct entry of such information as the date, drawing number and contact numbers. Figure 2 shows a page of coded information for tickets received in a study of No. 4A toll offices. Arbitrary codes are used only for indicating the office, class of report, trouble type, and to some extent, the apparatus type. For apparatus designated by a number, as in the case of the 280-type relay, that number is entered directly. Lettered types, however, are coded.

The tickets, in general, can be coded quickly and easily by this system. Every study, however, includes tickets with inconsistencies, obvious errors, incomplete information, or statements that require further clarification. Tickets, therefore, must be inspected individually before they are coded, and those raising questions that cannot be resolved are sent to the study office either for more information or for explanations.

TABLE 1—NO. 5 CROSSBAR SYSTEM—RELAY TROUBLES

		Number of Troubles per 1000 Relays per Year				
Relay Type	*No. of Relays in Study Offices*	*Open Contacts*	*Other Contact Troubles*	*Adjustment Troubles*	*Defective Relays*	*Total Troubles*
U or Y	229,098	2.8	0.1	0.3	0.1	3.3
EA	63,238	*	—	0.1	0.2	0.3
263,264	16,619	0.5	0.2	0.7	0.1	1.5
Polar	6,151	8.5	1.5	7.6	0.5	18.1
Mercury	4,608	—	—	—	3.5	3.5
Other	19,614	1.1	0.2	2.8	0.4	4.5

* Less than 0.1

After the cards have been punched, business machines sort and summarize them. The figures provided by these summaries are used to compute trouble rates — the number of troubles related to the amount of equipment or number of calls handled. Table 1 shows a typical summary of trouble rates for different types of relays, taken from a systems study conducted in No. 5 crossbar offices.

To understand the significance of trouble rates, many factors must be considered, such as the kinds of functions performed, whether troubles occurred in normal operation or were identified by routine testing, and whether the troubles occurred in circuits having a high or low frequency of operation. Figure 3 is a chart prepared for study of the relationship between open-contact trouble rates and the activities in progress in the offices. Such activity, by adding to the dust in the air, may cause an increase in the number of open contacts.

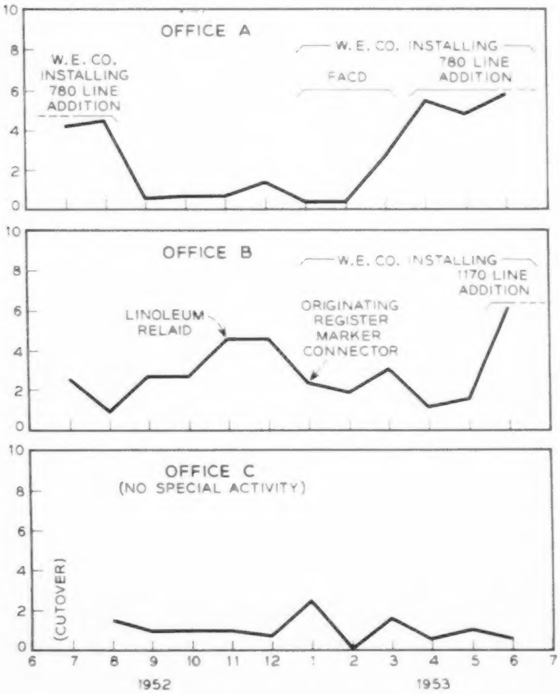


Fig. 3 — Portion of chart of U and Y open-contact troubles prepared to show the effect of installation activity on trouble rates in three telephone offices.

Analysis of the data also includes statistical checks on the consistency of the results from the individual offices. A control chart for "defects per unit" is used to spot instances where the data from a particular office, because of unusual conditions, may deviate too far from the average to be representative of the system as a whole. Such data may be excluded from the study results.

The final report presents summaries and includes pertinent, detailed data for areas of particular interest. It also discusses probable factors affecting malperformance and states conclusions. Engineers sometimes request additional details on particular types of trouble. Such data may come from summaries already made. If desired, the trouble tickets involved can be identified from the punched cards and drawn from the file for examination.

Significant results, at times unpredictable by other methods, have been obtained from these studies. In one case, results indicated the need for further study of a particular type of relay, with resulting changes in design. Frequently, of course, data affirm the success of design work by showing consistently low rates of trouble. Study results have contributed to the search for improved reliability of telephone switching equipment, and provide a background of reference data for estimating expected trouble rates in new design and development work. The nature of the data, combined with the details available, makes these studies a valuable source of information for many uses.

THE AUTHOR

Mrs. Charlotte H. Hamilton, a native of New York City, joined the Development and Research Department of the A.T.&T. Company after receiving a B.S. degree from Teachers College, Columbia University, in 1924. She became a member of the Laboratories in 1934. Her work has been concerned primarily with central-office maintenance problems, and she has conducted performance studies in toll and local switching offices and in AMA centers. Her work during World War II included the writing of instructions for the maintenance and testing of communications equipment for the armed services.

Line Verification in No. 5 Crossbar

E. G. CRANE, JR. *Switching Systems Development*

In automatic telephone switching systems, thousands of electrical connections must be accurately established and frequently revised. A new circuit has been developed for verifying the integrity of cross-connections in No. 5 crossbar offices — equipment which allows the frameman to perform his functions faster and more conveniently than was formerly possible.

For the purpose of dialing calls or billing customers, a telephone is identified by its number appearing on the telephone instrument – the directory number. In a No. 5 crossbar office the same telephone line is also identified, for switching purposes, as a location on a particular line-link frame – the frame of crossbar switches that comprise the first stage or last stage of automatic switching in the office. This information consists of a series of numbers specifying (1) the line-link frame on which the telephone line appears, (2) the horizontal group of crossbar switches, (3) the vertical section of the crossbar switches called "vertical group," and (4) the "vertical file." The vertical file number refers to a particular line in the vertical group, and thus completes the identification of the telephone line.

This series is known as the "equipment number," and it has no fixed relationship to the directory number. In fact, the arrangements are designed for "full flexibility," whereby any directory number can be associated with any equipment number. This permits telephone traffic to be distributed evenly throughout the line-link frames to obtain a uniform grade of service to all customers.

Fig. 1 — Control unit of line-verification equipment for No. 5 crossbar system; author, left, and R. J. De Dona of the N. Y. Telephone Company setting up line tests.

Flexibility of equipment number-versus-directory number, however, requires the initial installation of certain wiring on a "custom basis" for each telephone. Thereafter, occasional revision of this wiring is required to maintain a balance of traffic or to process service orders. These wires, called cross-connections, are so arranged that they may be changed quite easily. Checking them for correctness is called line verification.

Prior to development of the new line-verification equipment, verification tests were made by using the master test control circuit, which is part of the master test frame in a No. 5 crossbar office. In many offices, there are periods when this frame is almost continuously in use by maintenance personnel making routine operational tests on markers, registers, senders, trunks or other units of equipment. Thus, verification tests of cross-connections add to the work load of the maintenance center. To relieve this congestion, and at the same time to make the testing of cross-connections convenient to the frameman who actually installs them, a separate line-verification facility has been developed. This verification facility duplicates but does not replace the verification features of the master test frame in the office.

For the purposes of translation, cross-connections are located in the number-group, line-link frame, and AMA translator. The cross-connections of the number group are used for translating the last four digits of the directory number to its corresponding equipment number, and also the ringing combination and office-code group. The cross-connections of the line-link frame are used for indicating the class of service assigned to a vertical group and vertical file. The AMA translator cross-connections are

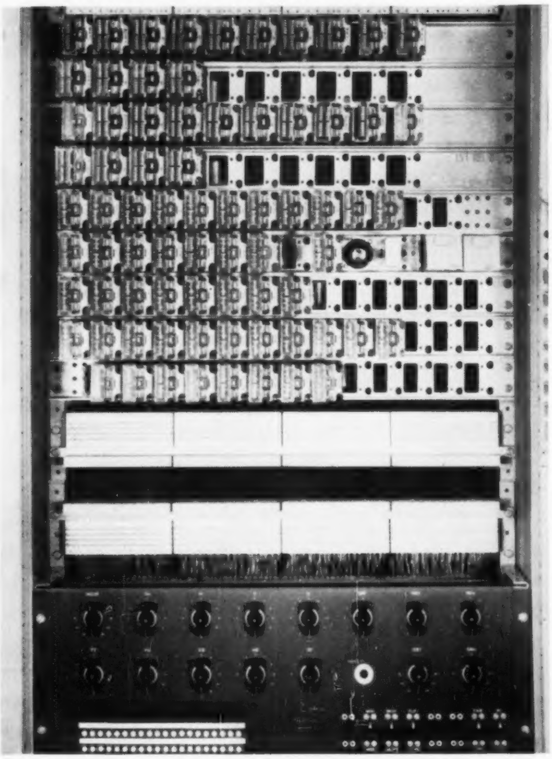


Fig. 2 — Relay unit and control unit of the line-verification equipment mounted on same frame.

used for translating an equipment number to a directory number, which is just the reverse of the number-group translation.

Cross-connections are removed, added, or changed to concur with disconnected, new, or relocated telephone service. Since an error in any cross-connection will result in a wrong number, it is important that these leads be installed correctly. With this new verification circuit, cross-connections may be checked immediately by the frameman after he installs them.

The apparatus of the line-verification circuit is mounted on two equipment units, one called a "control" unit and the other a "relay" unit. The control unit is a panel 12 inches high on which are mounted switches, keys and lamps. This unit can be mounted on a wall, the end of a distributing frame, a desk, or a relay rack. Figure 1 shows the mounting arrangement at the central office in Tuckahoe, N. Y.

The relay unit is 32 inches high; it accommodates nine mounting plates and may be mounted together with the control unit, or it may be mounted remotely from the control panel. Wire-spring relays are used. Figure 2 shows the relay unit mounted in the upper part and the control unit mounted with it in the lower part of the frame.

The line-verification circuit operates on the principle of "matching." Information requiring translation is sent to a marker for obtaining translation from a number group or to a transverter for obtaining translation from an AMA translator. At the same time, however, the known translation of this input information is preset on switches in the verification or test circuit. When the returned translation is the same as that on the preset switches in the test circuit — that is, when the two items of information match — a "check" relay is operated in the test circuit for that particular cross connection. When check relays have operated for each cross connection associated with the particular line being tested, a verification match results.

For example, if the directory number 9753 is to be verified, this number would be set up on the "thousands," "hundreds," "tens" and "units" switches of the verification circuit. Along with this information, the corresponding equipment number, which is obtained from office records or the service order, is preset on switches of the verification-circuit panel. Such equipment numbers are represented, for example, as "VG2" (vertical group

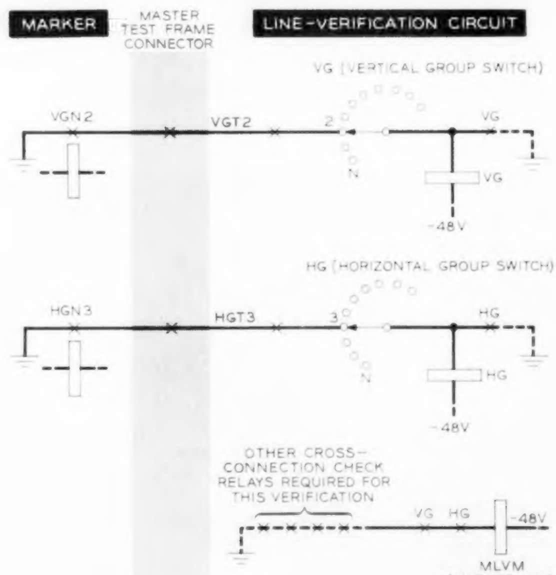


Fig. 3 — The "matching" principle: simplified diagram shows verification of cross-connection in number group of a No. 5 crossbar system.

number 2), "HG3" (horizontal group number 3), and so on.

A partial verification circuit is shown in Figure 3, which illustrates a case wherein it is desired to verify that a number-group cross-connection serving the directory number 9753 is valid. The No. 5 crossbar marker takes the 9753, selects the proper number group, and receives back the proper equipment number translation. Figure 3 shows circuitry for only vertical group "2" and horizontal group "3." The VGN2 and HGN3 relays are merely two of the many relays that operate in the marker as the result of this translation. The verification circuit has access, through the preset VG and HG switches seen in the right part of Figure 3, to the corresponding VGN2 and HGN3 relay-operating paths in the marker. Thus, the VG and HG relays (extreme right in Figure 3) will operate and lock locally in the verification circuit. To obtain an over-all verification check, all relays associated with cross-connections must be operated in this manner in the verification circuit, and ground is thereby closed to operate the MLVM (marker line verification match) relay. If one of the cross-connections – say horizontal group – is installed incorrectly, the HG relay-operating path in the verification circuit would be opened. The reason for this is that no other lead would pass through the HG switch, since this switch has been preset to the HG3 position. Thus, the HG relay in the verification circuit would not operate, which prevents the MLVM relay from operating. In this case, a lamp would light on the control panel to indicate that the incorrectly installed cross-connection was the one associated with the horizontal-group information.

This verification circuit has access to either of two marker groups. By virtue of the fact that the marker is used for access to the number-group and line-link frame cross-connections, this function is called "marker line verification" or MLV. Similarly, since the transverter is used for access to the translator cross-connections, this function is called "transverter line verification" or TLV.

The new verification circuit fits into the No. 5 system as shown in Figure 4. With this block diagram and the flow numbers – the numbers on the diagram indicating each step in the call – the operational sequence of making a line-verification test may be followed.

If the verification is to be of the MLV or marker line verification type, the office-designation information and the number of the line to be verified are preset on switches to be transmitted to the marker for use by the number group. At the same time, the correct line location, ringing combination and class-of-service information for that line are also preset on the control panel.

At the beginning of each test, a bid is made for test preference in the master test frame connector (1). This is necessary since this test circuit uses the master test frame and test relays in the markers and transverters in common with other test circuits. If no other circuit has access to the master test frame connector at this time, or when other circuits which had access to the master test frame connector become idle, preference is given the line-verification circuit. All other circuits which would cause interference are locked out of the master test frame connector.

The line-verification circuit connects, via the master test frame connector, to a marker within the particular group (2) and transfers the number and office code group designation to the marker in the same manner as an incoming register. The marker connects to the proper number group (3)

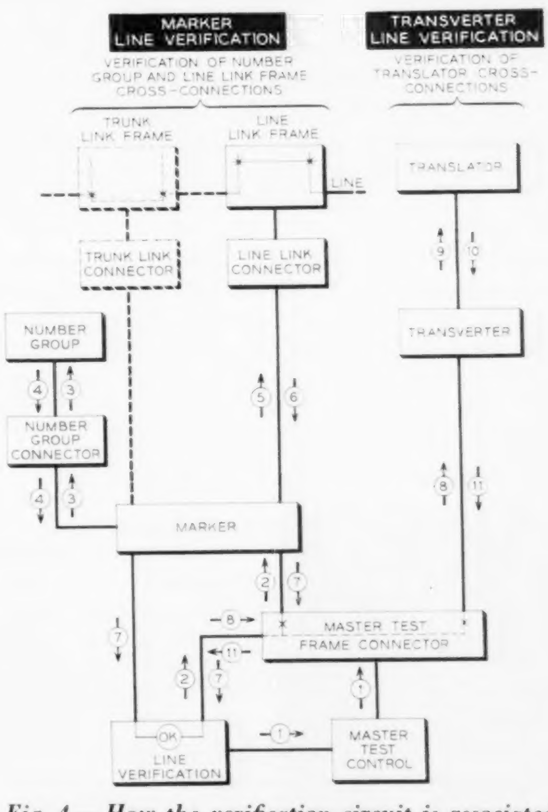


Fig. 4 — How the verification circuit is associated with other circuits of the No. 5 crossbar system; the numbers indicate steps in the test sequence.

Fig. 5 — Verification circuit conveniently located at right enables checking of the maze of cross-connections in number group frames at left and AMA translator frames at the center of the photograph.

and transfers the number to it. The number is translated into a line location and ringing combination which the marker requires, and this information is returned to the marker (4). Using the line-location information, the marker connects to the line-link frame (5) and attempts to set up a connection in the normal manner.

The marker has recognized that this is a test call and therefore does not complete the call to the line. From the marker action, however, the class-of-service information is obtained from the line-link frame by the marker (6). Since the verification circuit has access to the leads over which the marker receives the information from both the number group and line link frame (7), a verification lamp is lighted if the settings of the corresponding switches agree with this information. If one or more cross-connections are in error – thereby causing wrong information to be returned from the number group or line-link frame – a lamp is lighted to indicate the particular wiring error that is involved.

The AMA translator cross-connection check may be made independently of a marker line verification, or the verification circuit may be arranged to recycle directly to the TLV stage immediately following a succesful MLV verification. The line location and number of the line are preset on the same switches used in MLV. The office index, which consists of a single digit in lieu of the first three digits of the seven-digit directory number, is also set on a rotary switch. In a manner similar to that of the MLV test (1), the line-verification circuit connects to a transverter and transfers to it the line location (8). The transverter in turn transfers this line location to the selected translator (9). The translator translates the line location into an office index and a four-digit directory number, and then transfers these back to the transverter (10). If this information matches the office index and directory number previously preset on switches, an "OK

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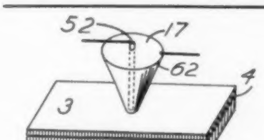
E. G. CRANE, JR., a native of Trenton, N. J., received a B.S. degree in Electrical Engineering at Duke University in 1942. After a period with the General Electric Co., he served during World War II as a Navy airborne electronics officer. Immediately thereafter he joined the N. J. Bell Telephone Company where he was concerned with central office power plant equipment engineering. In 1951 he transferred, on loan, to the Laboratories at Whippany, where he was involved with the development of a military system for the Navy. In 1953 Mr. Crane transferred to West Street where he became concerned with the development of the No. 5 crossbar system, particularly in the application of wire-spring relay circuits. The following year he became a permanent member of the Laboratories and in recent years has been involved with circuit development of maintenance facilities. He is a licensed professional engineer and received a M.S. degree from Stevens Institute of Technology in 1949.

match" indication is given by a lighted lamp (11). If a mismatch exists, which indicates that the installation of a cross connection was incorrect, a lamp is lighted to indicate the office index or directory number that is involved in the mismatch.

Although the end result of tests with this equipment is primarily a visual display to indicate a particular line verification, the circuit also has the ability to leave behind a permanent record of a verification if one is desired. This is produced on the office trouble recorder and is obtained by operating the record REC key at the control panel of the verification equipment. When the REC key is operated, upon each OK verification, a request is sent to the marker or transverter for a record. A record card is produced by the trouble recorder with all the pertinent information – line number, equipment number, date and verification check. If desired, this information may be filed by the Operating Company as a permanent record of the line verification for future use in the central office.

A field trial of this equipment has been successfully conducted at the Tuckahoe office of the New York Telephone Company. The control panel at Tuckahoe is located at the end of the main distributing frame, which is approximately midway between the number group and AMA translator frames. The relay panel is mounted on the miscellaneous relay rack on another floor. Since this office has all number groups, line-link frames and AMA translators on one floor and the maintenance center on another floor, and further, since there are two marker groups, it provided an excellent opportunity to observe the test circuit under conditions where it is most needed. It proved to be very reliable, and its performance was most satisfactory. The trial also demonstrated the desirability for a frameman to check his cross-connections immediately after installation without interrupting other testing at the maintenance center.



Patents Issued to Members of Bell Telephone Laboratories During January

Abbott, H. H. – *Station Identification Device* – 2,820,100.

Abbott, H. H. – *Subscriber Line Concentrating System* – 2,820,103.

Barney, H. L. – *Transmission and Reconstruction of Artificial Speech* – 2,819,341.

Becker, F. K. – *Monaural-Binaural Transmission of Sound* – 2,819,342.

Berkery, E. A. – *Current Supply Apparatus* – 2,820,941.

Bogert, B. P. – *Stereophonic Reproduction of Sound* – 2,819,348.

Bond, W. L. – *Automatic Recording Diffractometer and Plotter* – 2,819,405.

Bowman, B. M., and Rieke, J. W. – *Polarizing Circuit for Television Signals or the Like* – 2,820,181.

Feinstein, J. – *Magnetron* – 2,821,659.

Field, L. M. – *High Frequency Amplifying Device* – 2,820,172.

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Fuller, C. S. – *Method of Fabricating a p-n Junction* – 2,819,191.

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Gorgas, J. W., Jacobitti E., Jaeger, R. J., Jr., Morrison, C. G., and Newsom, J. B. – *Trouble Recording on Time-Out Circuit for Automatic Telephone* – 2,820,099.

Hey, H. C. – *Balanced Modulator* – 2,820,949.

Jacobitti, E., see Gorgas, J. W.

Jaeger, R. J., Jr., see Gorgas, J. W.

Kennedy, J. B., and Mallery, P. – *Firing Circuits for a Cold Cathode Gas Tube* – 2,820,926.

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Mallery, P., see Kennedy, J. B.

McCandless, C. H., see MacPherson, D. H.

Meyers, S. T. – *Impedance Measuring* – 2,820,195.

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Minks, F. A. – *Fuse Alarm Systems* – 2,821,697.

Morrison, C. G., see Gorgas, J. W.

Newhouse, R. C. – *Deflecting System* – 2,821,657.

Newsom, J. B., see Gorgas, J. W.

Newsom, J. B., see MacPherson, D. H.

Oliver, J. W., see Germanton, C. E.

Reiss, H., see Fuller, C. S.

Rieke, J. W., see Bowman, B. M.

Rieke, J. W. – *Relay Circuit* – 2,820,157.

Robertson, G. H., and Walsh, E. J. – *Multihelix Traveling Wave Tubes* – 2,821,652.

Robertson, S. D. – *Spatial Harmonic Traveling Wave Tube* – 2,820,170.

Shoffstall, H. F. – *Signaling Transmission Test and Control Circuit* – 2,819,354.

Townes, C. H. – *Molecular Resonance Modulators and Demodulators* – 2,819,450.

Walsh, E. J., see Robertson, G. H.

Whelan, J. M. – *Method of Purifying Silicon Tetrachloride and Germanium Tetrachloride* – 2,821,460.

Antenna Filters for a Military Radio System

M. D. BRILL AND R. M. JENSEN
Transmission Systems Development II and Merrimack Valley Laboratory

In supplying radio channels for the AN/TRC-24 military telephone system, it was necessary to design filters for use between the antenna and transmitter and between the antenna and receiver. The coaxial type of design resulted in a small, efficient package, and it was found possible to divide the entire 50 to 600 megacyles range into only twenty-two sub-bands, with each filter suitable for transmission and reception.

Some unknown radio engineer once observed that the worth of a radio receiver is judged not by what is received but by what is rejected. He was probably a transmitter designer who was plagued by complaints that his transmitter caused interference in receivers that he considered insufficiently selective. The receiver designer similarly might have said that the worth of a radio transmitter is judged not by what is transmitted but by what is suppressed. Such epigrammatic statements, only partially true and intended to impress and possibly to confuse, merely emphasize the importance of the "selectivity" of the device. This may be defined as the ability of the receiver (or transmitter) to receive (or transmit) the desired radio frequency signal, while preventing the reception (or transmission) of unwanted frequencies.

The AN/TRC-24 radio set, described in previous RECORD articles,* consists of a tunable transmitter and receiver, each with moderate RF selectivity. Additional selectivity must be supplied by tunable-frequency filters inserted between the final amplifier of the transmitter and the transmitting antenna, and between the receiving antenna and the receiving preselector.

*RECORD, *August*, 1955, *page* 290; *October*, 1955, *page* 382.

Figure 1 is a block schematic showing the circuit location of the filters. It is a characteristic of such filters that the greater the tuning range, the greater their complexity for a given amount of selectivity. The tunable ranges of AN/TRC-24 are the "A" band, 50-100 megacycles; "B" band, 100-225 mc; "C" band, 225-400 mc; and "D" band, 400-600 mc. Filters, tunable over each of these bands and furnishing the required selectivity, would be large, mechanically intricate, and expensive. A better solution, and the one adopted, is to divide the bands into smaller sub-bands and to design filters for each sub-band. In this way each filter tunes and provides selectivity over a relatively narrow sub-band, which considerably reduces mechanical complexity, size and cost.

The scheme has its unattractive aspect, however. Since several filters are used to cover a main tuning band, the selection of a filter is dependent upon the frequency to which the transmitter or receiver is tuned. The appropriate filter is plugged into the radio-frequency head of the transmitter or receiver, the others lying idle and creating a storage problem. Since the transmitter and receiver frequencies are not changed too often, however, plug-in filters do not impose a severe operational difficulty.

The "A," "B," and "C" bands are covered by six filters each, while the "D" band uses four filters. The filters for the transmitter must pass 100 watts of RF power without undue dissipative loss or temperature rise. The receiver filters must pass only

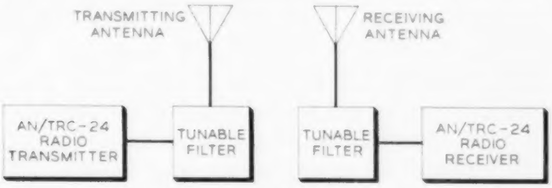


Fig. 1 — Location of tunable filters in AN/TRC-24 radio military telephone system.

extremely small amounts of power; however, they are made identical to the transmitter filters to minimize the number of distinct designs. Actually, because the transmitting and receiving frequencies used at any given location are different, a single set of filters is normally sufficient for a complete installation. Plug-in dummy filters are supplied with the radio equipment. When additional selectivity is not needed, the radio sets may be operated without filters.

The filter circuit that appeared best able to satisfy the electrical requirements is shown schematically in Figure 3. In the formula shown along

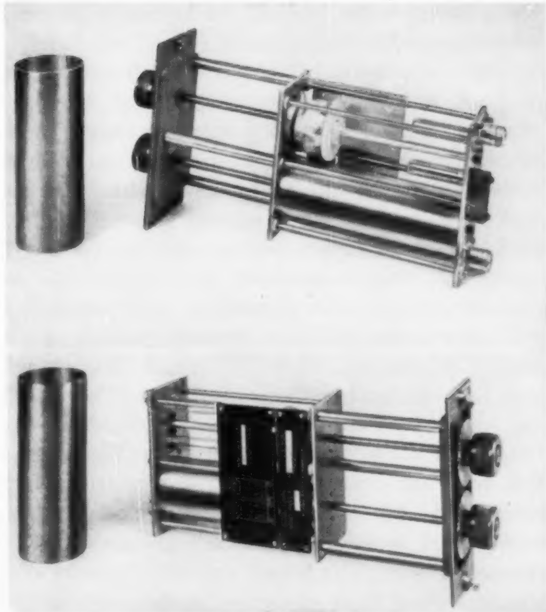


Fig. 2 — Two views of typical filter; outer cylindrical part of one coaxial section has been removed to show features of the internal structure.

with the diagram, R_o is the impedance of the circuit into which the filter works, and f_r is the midband frequency of the filter's pass-band.

It should be realized that f_r changes as the filter is tuned over its own sub-band. For design purposes, f_r is chosen as the middle of the sub-band, which of course means that the design is theoretically ideal only when the filter is tuned to the center frequency. But since the sub-bands are not unduly wide, the departure from the ideal is small, even when the filter is tuned to the edge of its sub-band. An advantage of this type of circuit is that by the use of coupling coils the designer may choose the impedance level of the resonant circuits for structural convenience, and then select

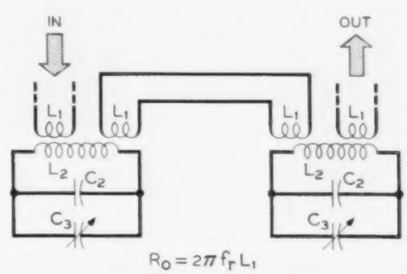


Fig. 3 — Circuit for the tunable filter; coaxial-type units are used for L_2-C_2-C_3 resonant circuits.

the coupling factor to yield the best over-all transmission performance.

After appropriate theoretical designs were evolved, it was necessary to translate them into physical elements. The frequency range under consideration, 50 to 600 megacycles, is not well suited to the design of lumped-element filters – that is, filters consisting of the conventional capacitor and inductor components. At these frequencies, lumped elements involve troublesome parasitic effects from connecting leads, and it is difficult to construct them in convenient sizes possessing adequately high "Q" (small dissipation), and high power-handling capability. The 50-600 mc frequency range, however, is well-adapted to the use of filters of the coaxial type. Elements of this type are comparatively free from the aforementioned objectionable features of lumped elements, and in addition are self-shielding and of reasonable size. The filters, accordingly, were constructed using these elements for the resonant circuits designated L_2-C_2-C_3 in Figure 3. The coupling inductances, L_1, were made in the form of a single-turn loop, since extremely high "Q" is not required of them. The input and output coupling

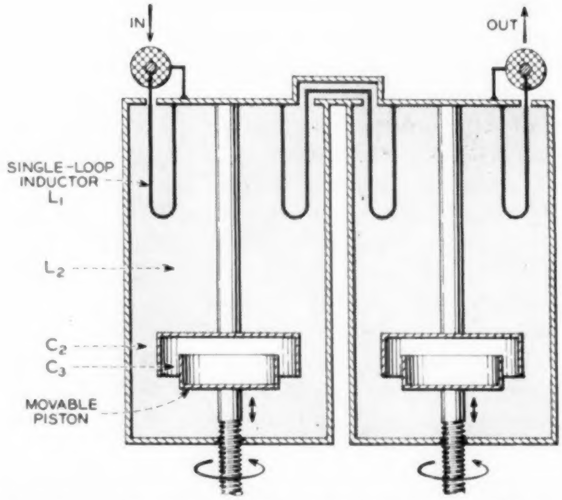


Fig. 5 — A more pictorial representation of the coaxial sections; labels identifying inductances and capacitances are identical to those on Figure 3.

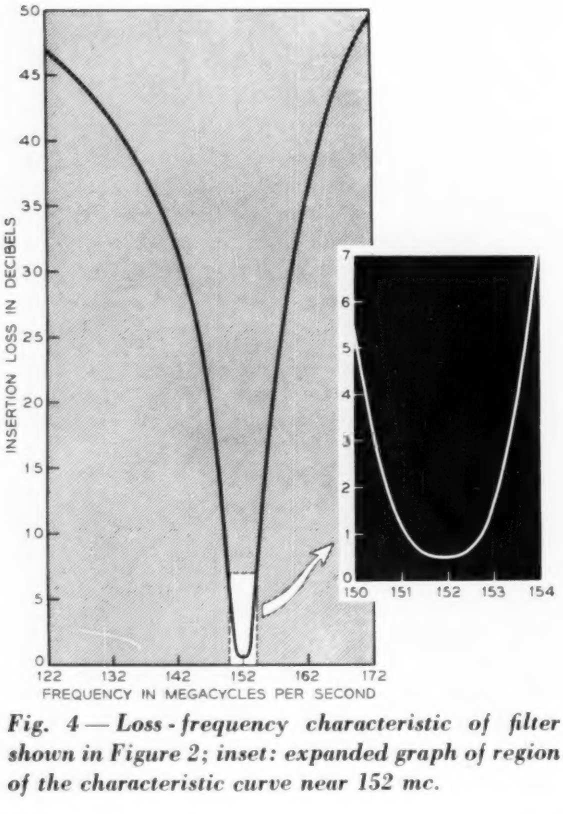


Fig. 4 — Loss-frequency characteristic of filter shown in Figure 2; inset: expanded graph of region of the characteristic curve near 152 mc.

inductances to a cavity are positioned to effect a minimum coupling between them, which permits the filters to realize the maximum out-of-band discrimination.

Figure 2 shows a typical filter with one of the outer coaxial conductors removed for display purposes. If this illustration is viewed in combination with the schematic diagram, Figure 3, the component elements may be identified and the coaxial type of construction is evident. For example, the adjustable coaxial capacitors, C_3 of Figures 3 and 5, tune the filter to the required frequency. This particular filter has a useful tuning range of 142 to 163 megacycles per second. Figure 4 is an insertion-loss characteristic of the filter when tuned to the frequency 152 megacycles per second. The band loss is small, since the "Q" of the coaxial elements is high. The out-of-band discrimination, or selectivity, more than satisfies the design requirements for the system.

Coaxial filters of this type may be expected to display spurious pass bands at frequencies appreciably higher than their nominal pass bands where the coaxial lines become resonant again. For the filters described, this occurs at frequencies of small importance; furthermore, the spurious pass bands are by no means freely transmitting. The frequency scale of Figure 4 does not extend sufficiently high to show any of these bands.

After achieving an appropriate electrical design, it is necessary to design a suitable mechanical structure. Such a structure must be accurately dimen-

sioned to provide accurate electrical properties and, in addition, must be ruggedly constructed to withstand shock and vibration of transportation, and severe weather conditions. Further, the structure must be of a form that can be economically manufactured in large quantities, and of a form that can readily be plugged into the radio-frequency heads of the transmitter and receiver. All of these features are incorporated in the structure shown in Figure 2, which is the basic structure used in all filters.

The dial mechanism is of a special design; it has the axial motion required to vary the capacitance of the coaxial capacitor used to tune the filter. Simultaneously, the mechanism drives a dial plate which is calibrated in terms of the various channels and frequencies used for the radio transmission.

When the filters are not in use they are housed in convenient transit cases. These cases are similar in design and construction to the ones used for the transmitter and receiver. They provide protection against adverse environmental conditions during transportation and storage.

Electrical and mechanical tests were applied to representative models of these filters by the U. S. Signal Corps. The filters performed excellently, and quantity production by the Western Electric Company was undertaken. Although expressly designed for the AN/TRC-24 radio set, the Signal Corps has found them useful in a variety of other applications.

THE AUTHORS

M. D. Brill, a native of New York City, joined Bell Telephone Laboratories in 1930 after receiving the A.B. degree and the A.M. degree in Physics from Columbia University. At the Laboratories he has been principally engaged in the development of communication networks for Bell System use, except for a period during World War II when he worked mainly on radio counter-measures devices. After the war, Mr. Brill assumed responsibility for a group designing microwave filters and networks for the TD-2, TH and TJ microwave radio-relay systems. For the past year he has been in charge of a group designing networks for military projects.

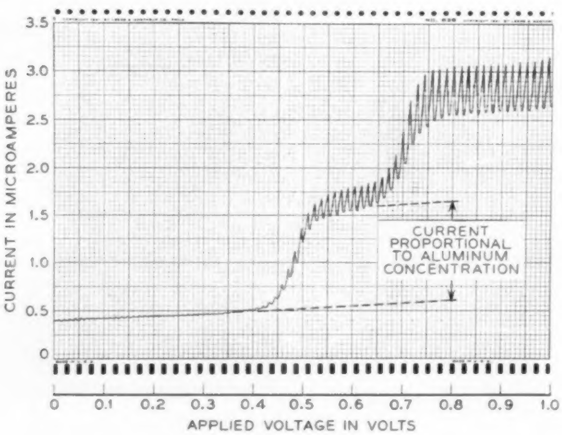
R. M. Jensen, whose home town is Hurley, South Dakota, received the B.A. degree from the University of South Dakota in 1934 and the B.S. degree from Purdue in 1937. He then joined the Laboratories and worked on the design of audio equipment, and subsequently worked in the Quality Assurance Department. In 1939 he transferred to the Transmission Networks Department where, during World War II, he designed amplifiers, oscillators and filter circuits. Later, he was engaged in the design of networks for carrier-telephone systems and tunable coaxial filters for the AN/TRC-24 radio-relay system. Mr. Jensen is currently engaged in the development of microwave apparatus for the TJ and TH systems, and of coaxial apparatus for a mobile radio system.

A New Analysis for Nickel Cathodes

P. D. Garn (left) and H. M. Gilroy examine polarograph to ascertain elements in a metal solution.

The behavior of an electron tube in a circuit depends to a large extent on the behavior of its thermionic cathode. Thus, an accurate analysis of the cathode metal aids in furthering the life expectancy of the tube. Long life is particularly advantageous for electron tubes that are used in such inaccessable equipment as the recently installed underseas cables.

The nickel used in cathode material contains impurities that affect the ease and degree of activity and the emission life. For example, certain elements such as magnesium or aluminum are believed to enhance the tube behavior, while other elements such as silicon or manganese may have an adverse effect. It is important to know accurately the constituents of cathode metal so that cathode behavior can be correlated with the amount of impurities. With such information, manufacturers can select proper alloy combinations to produce tubes with longer life and higher thermionic activity.



Analysis of aluminum. The first increase in current indicates the reduction of an aluminum-dye complex. The second increase indicates the reduction of the uncomplexed dye. The closely spaced peaks are caused by the formation and falling away of individual drops of mercury.

At Bell Laboratories a study has been made to determine the most accurate method of analyzing samples of manufactured cathodes. These samples are analyzed after fabrication to determine what impurities remain after chemical reactions associated with the manufacturing process have taken effect on the original nickel alloy. These reactions include processes such as absorption and segregation, and they also include the effects of a volatile substance.

The most rapid technique for this analysis employs the spectrograph for the determination of the presence of extraneous substances in nickel cathodes. In this method, the entire cathode is converted into an oxide and mixed with appropriate buffering agents. The resulting powder mixture is packed into a crater in a graphite rod. This composite is brought into contact with a second graphite rod. An applied dc potential across these two "electrodes," as the interval between them is opened, maintains an arc. Radiation from this arc is viewed through a prism which scatters (spreads out and separates) the light in a large number of characteristic wavelengths or colors. The scattered light is intercepted either by a photographic plate or by photocells. By studying the spectrum, the chemist can detect the presence of elements from the number and color of lines observed. He can also measure the quantity of these elements from the intensity of the color lines.

In searching for a more accurate technique, P. D. Garn and H. M. Gilroy of the Laboratories Chemical Research Department have investigated another way of analyzing nickel cathodes – the method of polarography. They have found this method to be feasible, and thus have improved the average accuracy from five per cent with spectrography to one or two per cent with polarography. A further advantage of this method is that no standards similar to the sample are required. Each impurity is determined independently, and the presence or absence of any other element has no effect on an individual determination.

The polarograph uses the characteristics of current-voltage curves to mark the existence and amount of an element in a solution. To determine the cathode constituents, the metal is dissolved in solution. A series of precipitations, filtrations, evaporations, electrolyses, and additions of compounds separates the solution into workable sub-solutions that are studied polarographically.

A pair of electrodes – a polarizable cathode and non-polarizable anode – are immersed in the solution to be studied. The electrodes are connected to an external circuit, which includes a pen-recording apparatus. A voltage is applied and is steadily increased.

At a particular voltage the current flow suddenly increases rapidly. This "polarographic wave" is due to the reduction (change in valence state), of the ion at the cathode. Each element has a characteristic reduction potential and the voltage at which the current suddenly increases can be used to identify the ion. The current does not increase indefinitely because the supply of ions in the immediate vicinity of the cathode is quickly removed. The current is limited, therefore, by the rate of diffusion of the ions to the cathode surface. The rate of diffusion, and thus the current, is proportional to the concentration of the ion in the bulk of the solution.

Determining the presence and amount of iron and manganese in the nickel alloy represents a novel analytical method. The addition of triethanolamine to solutions containing these two elements results in an improved constant current and, in turn, an improved definition of the polarographic wave that represents the ions.

Western Electric Annual Report Shows 1957 Progress

The Western Electric Company's total sales in 1957 were $2,480,614,000, an increase of 4.5 per cent over 1956, according to the annual report to stockholders, published February 21. Sales to Bell Companies reached a high of $1,821,198,000, a 10.5 per cent increase over 1956 sales.

This is the largest volume of business ever handled by the Company in a single year, although changes toward the end of the year by the Bell Companies in many of their construction programs caused a leveling off in Western Electric production and service activities.

About one quarter of total sales, or $575,175,000, was to the Government for materials and services related mainly to national defense projects, among them the Distant Early Warning Line, in the Arctic, which was completed in July; the White Alice System, in Alaska; and production of the Nike ground-to-air missile system.

Despite some downward revisions of the Company's production program in the final months of the year, output of many types of telephone products exceeded 1956 peaks. By the end of the year 6,668,000 telephone sets, 134,500 million conductor-feet of exchange cable and enough dial central office switching equipment to serve 3,822,000 lines were shipped. Company installers worked on some 60,000 projects in 7,200 cities and towns throughout the United States, setting new records for installing, testing and readying for the Bell telephone companies' use, switching and other equipment for 3,614,000 dial lines.

The Company made purchases directly from about 33,000 companies, 90 per cent of them small businesses. In addition, transportation services were provided by 3,000 other firms. The total paid by Western Electric in 1957 for materials, parts, supplies and transportation was $1,224,000,000.

In connection with development of the Company's technological resources during 1957, the annual report makes special note of the establishment of the Graduate Engineering Training Program and of the first steps toward establishing an engineering research center at Hopewell Township, N. J.

Dataphone Service in Three Bell System Areas

At the request of the A.T.&T. Co., Bell Laboratories has developed equipment for trials of a new communications service. During February, the new service—called "Dataphone"—was offered on a limited basis in three Bell System areas: Illinois Bell, Michigan Bell and the New York Company.

Dataphone, which could be one of the most significant business developments of our times, is a high-speed transmission service for sending and receiving data over regular telephone lines (see RECORD, *April*, 1957, and *September*, 1957). It can send information over telephone facilities 10 times faster than present methods—about 800 words a minute.

Designed to send information to and from customers' data-processing machines in various locations, Dataphone service makes use of special devices – subsets – which can handle various types of business-machine codes. They interpret and transmit data read from punched cards, magnetic and paper tapes and other media. They can also transmit text. Subsets are manufactured by Western Electric.

Wherever there is a telephone there can be a Dataphone subset – one of the advantages of the new service. It can be plugged into a standard electrical outlet to get its source of power.

SPEEDS BUSINESS OPERATIONS

Dataphone service has a promising future. Eventually a person using the service will be able to transmit data to any point on the telephone network. It is also economical: a customer will pay for the service much as he would for regular telephone service. His main charge is based on how much he uses it.

V. N. Vaughan, Jr., of the A.T.&T. Co. demonstrating Dataphone subset equipment during press showing of the new systems for transmitting data over telephone lines.

A businessman in New York can pick up a telephone associated with a Dataphone subset and call another division of his company in Chicago. He tells his associate in Chicago he's going to send him some payroll data. Each presses a button on his telephone, and information starts flowing over the circuits from a business machine or from a tape prepared in advance. His charge for sending data is the same as for a regular long-distance telephone call.

If the businessman has several branches of his company scattered across the land, he can transmit data at high speeds to one or to all of his branches. Or people in his branch offices can take information from their electronic counterparts and send it back to headquarters.

Dataphone service can be provided at present using two kinds of subsets – the Digital Subset and the Recorded Carrier Subset. The *Digital Subset* converts electrical pulses of data received from originating equipment (computers or tabulators, for example) to audible tones for immediate transmission over telephone lines. At the receiving end, the reverse function is performed. The equipment takes the tones, reconverts them into electrical impulses and delivers the data to business machines.

The *Recorded Carrier Subset* through a tape recorder permits storage of information received from business machines for transmission at a later time. Pulses are accepted from the machines at relatively slow speeds and are recorded on magnetic tape. Subsequently, the Recorded Carrier Subset transmits the taped information to another subset at the receiving end at a speed eight times faster than the information was recorded. Thus, 24 minutes of information can be compressed into a three-minute call. At the receiving end, the procedure is reversed – the information is "played back" to business machines.

Also available are certain optional features not requiring attendance by operating personnel. For instance, information can be stored on a Recorded Carrier Subset throughout the day and transmitted during the evening from and to a master station. Thus, Dataphone makes it possible for machines

Left: a Digital Subset for immediate transmission of data; and right: a Recorded Carrier Subset which stores many types of data on magnetic tape.

to take advantage of lower long-distance rates at night.

A wide variety of business machines can be adapted to Dataphone equipment: card readers and punches, various paper and magnetic tapes, and teletypewriter equipment. As new commercial machines are developed, they can be designed to be used with Dataphone equipment.

Homer Dudley Honored For Audio Society Paper

The Audio Engineering Society has announced that Homer Dudley of the Laboratories has been awarded a Letter of Commendation for his paper "Fundamentals of Speech Synthesis." This paper appeared in the *Journal of the Audio Engineering Society*, Vol. 3, October, 1955.

In a letter accompanying the award, Mr. George Horiuchi, Editor of the Journal, cited Mr. Dudley for his work in speech synthesis. "In particular," Mr. Horiuchi stated, "the excellent paper which you contributed to our Journal was the subject for a great deal of favorable comment." Mr. Dudley, a member of the Visual and Acoustics Research Department, is the inventor of the original Bell Laboratories Vocoder machine for the study of speech transmission.

Oliver E. Buckley Award to Harvard Professor

The Oliver E. Buckley Solid-State Physics Prize for 1958 was presented during a recent joint meeting of the American Physical Society and the American Association of Physics Teachers. The prize, named for the former President of Bell Telephone Laboratories, was awarded to Dr. Nicolaas Bloembergen, Professor of Applied Physics at Harvard.

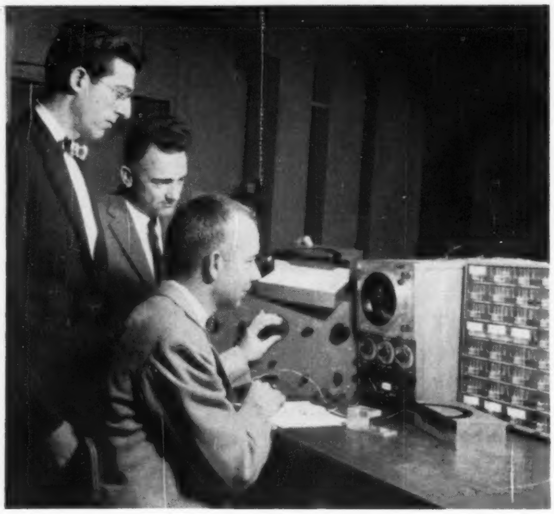
Bell Telephone Laboratories and the American Physical Society established the prize, which consists of an award of $1,000 to a person adjudged to have made a most important contribution to the advancement of knowledge in solid-state physics within the five years prior to the award. Dr. Bloembergen was the first to conceive a solid-state MASER capable of continuous operation.

New-Style Telephone "Booth"

A new open-shelf type of telephone "booth" has been developed in the Station Apparatus Development Department at Bell Laboratories and is now undergoing consumer tests at the Michigan and Chesapeake and Potomac Telephone Companies. The units, placed on trial through the A.T.&T. Co. Customer Products Planning Division, may some day provide supplements to regular booths in indoor locations, for example in department stores.

Western Electric Co. made the shelf units at the Queensboro, N. Y., Shop, and have turned out the test models in three colors, red, tan and green.

(Below) D. H. King of the Apparatus Development Department testing new "booth" at the Laboratories.



A Field-Effect Varistor

A two-terminal, passive semiconductor component having novel and highly useful characteristics was described on March 26 at the annual convention of the Institute of Radio Engineering in New York City. The experimental device, known as a field-effect varistor, was developed by E. I. Doucette, H. A. Stone and R. M. Warner, Jr. (above photograph, left to right).

This component has a constant-current feature which makes it ideally suited for a current regulator in circuits where either the load or supply voltage vary over wide limits. It can also be used as a current limiter or pulse shaper. Its ac impedance is very high, making it useful as a coupling choke or as an ac switch.

The device, closely related in principle to the field-effect transistor (see RECORD, *May*, 1955), contains a single planar junction which is made by the diffusion technique. Current passes parallel to this junction through a constricted region called the channel. As the voltage across the device is increased, current increases, and a depletion layer builds up which eventually "reaches through" the entire thickness of the channel. At this point, called the "pinch-off" point, a further increase in voltage does not produce any increase in current. Eventually an avalanche breakdown occurs, as the voltage is increased still further. Between pinch-off and breakdown, the current is essentially constant.

At present these varistors are fabricated by cutting dice from a slice of germanium or silicon containing a single diffused junction. The dice are heavily plated on all surfaces, and a circular trench is then cut into the diffused layer to within about 0.1 mil of the junction (see Figure 1). This cutting requires a high degree of precision, since the characteristics of the final device depend heavily on the spacing between the bottom of the trench and the junction. In exploratory work, the trench is first cut with an ultrasonic tool and finished to the desired depth by etching. Leads are then attached by thermo-compression bonding or other means.

Characteristics of the device can be altered by varying such parameters as channel depth, impurity gradient, length and width of channel, and selection of semiconductor material. Using silicon, units have been fabricated with a regulated current of one milliampere, pinch-off voltage of 10 volts and breakdown of 150 volts.

Current can be held constant to within one per cent over a voltage range of 20 to 120 volts. Germanium units have been made with a rating of 10 milliamperes, pinch-off of 10 volts and breakdown of 25 volts. It appears feasible at present to produce varistors which regulate current at any level between 10 microamperes and 10 milliamperes, and improvements in fabrication techniques should make higher current levels possible.

For circuit applications, a parasitic shunt capacitance of the order of a few mmfd. is present and must be taken into consideration. In the constant-current region, the ratio of ac resistance to dc resistance is typically 100 and may run as high as 1000, making it ideal as a coupling device. It differs from a conventional choke since impedance is constant over an appreciable frequency range.

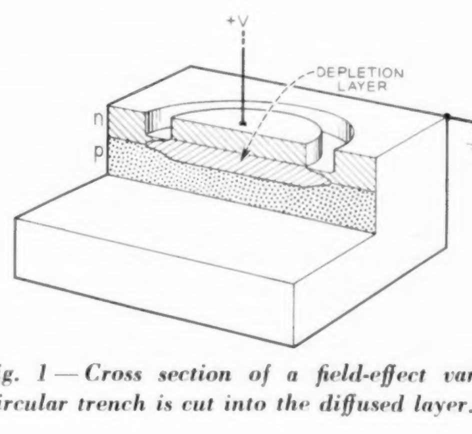


Fig. 1 — Cross section of a field-effect varistor. Circular trench is cut into the diffused layer.

U. S.-Puerto Rico Submarine Cable Planned for Service Early in 1960

Plans for construction of a direct submarine telephone cable system between the continental United States and Puerto Rico have been announced jointly by the Long Lines Department of American Telephone and Telegraph Company and International Telephone and Telegraph Corporation.

The announcement coincided with the filing of construction applications with the Federal Communications Commission seeking authority to build and operate the cable system.

The plans provide for work to start on the cable system in 1958, with service scheduled for early in 1960. The cost, according to present estimates, will be about $17 million and will be shared equally by Long Lines and Radio Corporation of Puerto Rico, a subsidiary of I. T. & T.

Telephone traffic between the mainland and Puerto Rico has more than doubled during the last five years. At the present time, telephone service is handled by radio.

Contents of the March, 1958, Bell System Technical Journal

The March, 1958, issue of THE BELL SYSTEM TECHNICAL JOURNAL contains the following articles:

Telephone, by E. I. Green.

Tone Ringing and Pushbutton Calling, by L. A. Meacham, J. R. Power and F. West.

Attenuation in Continuously Loaded Coaxial Cables, by Gordon Raisbeck.

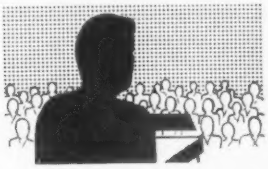
New Developments in Military Switching, by A. C. Gilmore, P. R. Gray and W. S. Irvine.

A Proposed High-Frequency, Negative-Resistance Diode, by W. T. Read.

Broadband Oscilloscope Tube, by D. J. Brangaccio, A. F. Dietrich and J. W. Sullivan.

Optimum Tolerance Assignment to Yield Minimum Manufacturing Cost, by David H. Evans.

The Measurement of Power Spectra from the Point of View of Communications Engineering — Part II, by R. B. Blackman and J. W. Tukey.



Talks by Members of the Laboratories

Following is a list of speakers, titles, and places of presentation of recent talks given by members of the Laboratories.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS WINTER GENERAL MEETING, NEW YORK CITY.

Ball, W. C., *Ground Measurement for Communication Circuit Protection Planning.*
Edson, J. O., see Perry, A. D.
Flavin, M. A., see Perry, A. D.
Gryb, R. M., *Recorded Carrier System for High Speed Data Transmission.*
Myers, O., *Modern Communication Switching Systems.*
Perry, A. D., Edson, J. O., and Flavin, M. A., *Synchronized Clocks for Data Transmission.*
Rose, D. J., *Ionization in Gas Switching Tubes.*
Ruppel, A. E., *Methods of Evaluating The Transmission Performance of the A1 Digital Data Signaling System.*
Shair, R. C., *Lead-Acid Batteries in Telephone Service.*
Smith, D. H., *A 1-Watt Solar Power Plant.*
Votaw, C. J., see Whitman, A. L.
Weber, L. A., *An FM Digital Subset for Data Transmission Over Telephone Lines.*
Whitman, A. L., Votaw, C. J., and Smith, C. W. (A.T.&T.), *The 83B1 Teletypewriter Selective-Calling System.*

THE 1958 TRANSISTOR AND SOLID-STATE CIRCUITS CONFERENCE, PHILADELPHIA, PA.

Early, J. M., *New and Future Solid State Devices, Their Properties and Application.*
James, D. B., see Myers, P. B.
Johannesen, J. D., see Myers, P. B.
Myers, P. B., James, D. B., and Johannesen, J. D., *A Two-Transistor Gate for Time-Division Switching.*
Saari, V. R., *Transistor 70-Mc IF Amplifier.*
Simkins, Q. W., *Transistor Resistor Logic.*

OTHER TALKS

Anderson, R. R., *Dynamic Design and Test Problems of Magnetic Tape Recorders*, Am. Soc. of Mechanical Engineers, Johns Hopkins University, Baltimore, Md.

Bennett, W. R., *Digital Transmission as a Random Process*, Electrical Engineering Department Seminar, M. I. T., Cambridge, Mass.

Berkery, E. A., *Power Supply Design Factors*, Ridgewood Amateur Radio Club of N. J., Hohokus, N. J.

Biondi, F. J., *The Cleaning of Parts for Electronic Devices*, Am. Soc. for Testing Materials, Washington, D. C.

Bozorth, R. M., *Modern Magnetic Materials*, Washington Section, A.I.E.E., Washington, D. C.

Brady, G. W., *Structure in the Vitreous and Liquid State*, Sigma Xi Society, Corning Glass Works, Corning, N. Y.

Brattain, W. H., *Development of Concepts in Semiconductor Research*, Cleveland Physics Society, Cleveland, Ohio.

Brattain, W. H., *Surface Physics of Semiconductors*, Journal Seminar, Physics Dept., Case Institute of Technology, Cleveland, Ohio.

Talks by Members of the Laboratories, Continued

Doherty, W. H., *Communication Looks to the Future*, Town Club, Milton, Mass.

Frisch, H. L., and Lloyd, S. P., *One-Dimensional Impurity Bands*, Am. Physical Soc., N. Y. C.

Frisch, H. L., *One-Dimensional Impurity Bands*, Physics Colloquium, Stevens Institute of Technology, Hoboken, N. J.

Geller, S., *Garnets – Crystal Chemical and Magnetic Studies*, General and Physical Chemistry Seminar, Cornell University, Ithaca, N. Y.

Gibbons, D. F., *Role of Dislocations in Plasticity*, Montreal Chapter, A. S. M., McGill University, Montreal, Canada.

Grossman, A. J., *Design of Networks*, I.R.E. New York Section and A.I.E.E. Basic Science Division, N. Y. C.

Hagstrum, H. D., *Electronic Transitions Between a Solid and an Approaching Ion*, Edison Laboratory, West Orange, N. J., and Catalysis Club, Chicago, Ill.

Harary, F., *The Number of k-Colored Graphs*, Am. Math. Soc., Cincinnati, Ohio.

Hersey, R. E., *Sixty Million Telephones at Your Fingertips*, Connecticut Valley Alumni Association, Phi Kappa Psi Fraternity, Hartford, Conn.

Jensen, A. G., *Efficient Use of Bandwidth*, Philadelphia A.I.E.E.-I.R.E. Lecture Series on Modern Communication, Philadelphia, Pa.

King, J. C., *Anelasticity of Synthetic Quartz at Low Temperature*, Am. Physical Soc., N. Y. C.

Kohman, G. T., *Crystal Growth*, Merck Chemical Co., Elizabeth, N. J.

Laudise, R. A., *Hydrothermal Growth of Crystals*, Am. Inst. of Chemical Engineers, University of Virginia, Charlottesville, Va.

Liehr, A. D., *The Coupling of Vibrational and Electronic Motions in Degenerate Electronic States*, University of Michigan, Ann Arbor, Mich.; University of Colorado, Boulder, Col.; and University of Chicago, Chicago, Ill.

Lloyd, S. P., see Frisch, H. L.

MacKintosh, I. M., *New Developments in Transistor Engineering*, Congregational Church, Scarsdale, N. Y.

MacWilliams, W. H., *The Use of Computers for Engineering Development and Design*, New York Section of the I.R.E. Professional Group on Engineering Management, N. Y. C.

Maggio, J. B., *Engineering as a Career*, Summit High School, Summit, N. J.

McMillan, B., *A Theory of Communication*, University of Pennsylvania, Philadelphia, Pa.

Mertz, P., *Information Theory Impact on Modern Communications*, Michigan Section A.I.E.E., Communications Technical Committee, Michigan State University, East Lansing, Mich.

Owens, C. D., *A Look at Modern Magnetics for the Engineers*, Merrimack Valley Subsection, A.I.E.E., Branch Hall, Lawrence, Mass.

Pierce, J. R., *Some Problems of Space Travel*, Federal Telecommunications Laboratories, Nutley, N. J.

Prince, E., *Neutron Diffraction Problems on Magnetic Oxides*, U. S. Naval Research Laboratory, Washington, D. C., and M. I. T., Lexington, Mass.

Quate, C. F., *Microwave Tubes – What is New?*, I.R.E. Subsection, White Plains, New York.

Rowen, J. H., *Fundamentals of Ferromagnetism*, Edison Research Laboratories, West Orange, N. J.

Slichter, W. P., *Characteristics of Rubber-Like Materials*, New York Rubber Group, Course on Advanced Elastomer Technology, N. Y. C.

Thatcher, W. H., *NIKE – A Guided Missile System for Anti-Aircraft Defense*, College Club, Linden, N. J.

Thomas, B. J., *How a Radar Works*, Williams High School, Burlington, N. C.

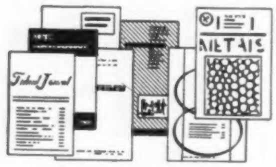
Vacca, G. N., *Comparison of Accelerated and Natural Tests for Ozone Resistance of Elastomers*, Am. Soc. for Testing Materials, Symposium on Ozone, St. Louis, Mo.

Winslow, F. H., *The Thermal Oxidation of Hydrocarbon Polymers*, Chemistry Seminar, Rutgers University, New Brunswick, N. J.

Winslow, F. H., *New Protectants for Hydrocarbon Polymers*, Pittsburgh Section, Am. Chemical Soc., Mellon Institute, Pittsburgh, Pa.

Wood, E. A., *Opportunities for Women in Industrial Research*, Douglass College, Rutgers University Career Forum, New Brunswick, N. J.

Wooley, M. C., *Components for Submarine Telephone Cable Repeaters*, Dayton Section I.R.E., Professional Group on Components, Dayton, Ohio.



Papers by Members of the Laboratories

Following is a list of the authors, titles and places of publication of recent papers published by members of the Laboratories:

Benson, K. E., see Wernick, J. H.

Bridgers, T. J., *A Parametric Electron Beam Amplifier*, Proc. I.R.E., **46**, pp. 494-495, Feb., 1958.

Eisinger, J., *Electrical Properties of Nitrogen Adsorbed on Tungsten*, J. Chem. Phys., **28**, pp. 165-166, Jan., 1958.

Ferrell, E. B., *Control Charts for Log Normal Universe*, 1958 Middle Atlantic Conference Transactions, pp. 137-142, Feb. 28-March 1, 1958.

Fletcher, R. C., *Physical Phenomena of the Solid State*, Proc. of the Symposium on the Role of Solid State Phenomena in Electric Circuits, **7**, pp. 41-62, 1957.

Geller, S., see Wernick, J. H.

Law, J. T., *The Interaction of Oxygen with Clean Silicon Surfaces*, J. Phys. and Chemistry of Solids, **4**, p. 91, 1958.

Mason, W. P., *Ferroelectrics*, Proc. of Symposium on the Role of Solid State Phenomena in Electric Circuits, **7**, pp. 91-108, Feb. 27, 1958.

Mayzner, M. S., and Tresselt, M. E. (NYU), *Shifts in Connotative Meaning of Words as a Function of Previous Restrictive Experience*, *J. of Experimental Psychology*, **55**, pp. 200-205, 1958.

McAfee, K. B., Jr., *Stress Enhanced Diffusion in Glass – I. Glass Under Tension and Compression – II. Glass Under Shear*, J. Chem. Phys., **28**, pp. 218-229.

McDavitt, M. B., *6000 Megacycles/Sec. Radio Relay System for Broad-Band, Long Haul Service in the Bell System*, Communication and Electronics, **34**, pp. 715-722, Jan., 1958.

Waite, T. R., *A General Theory of Bimolecular Reaction Rates in Solids and Liquids*, J. Chem. Phys., **28**, pp. 103-106, Jan., 1958.

Wernick, J. H., Geller, S., and Benson, K. E., *X-Ray Powder Data for Synthetic Proustite*, Ag_3AsS_3, Analytical Chemistry, **30**, p. 303, Feb., 1958.

Bell Laboratories RECORD